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Comparing interfaces for physically based character control

Master's Thesis
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ABSTRACT OF MASTER'S THESIS

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Increase in computational power in gaming has led to increased use of physical simulation to produce animated content for games. Physically based animation is still however, rarely used for animating characters under player's direct control, mostly due to difficulty of control.

The aim of this thesis was to find out whether the issues related to physics-based character control are related to the unintuitive control interfaces or if controlling them is complex in general. In awkward physics games, controlling a physically based animated character is part of the core gameplay. Finding out what factors make the control interface playable and engaging could provide insight to building interfaces for physically based character control. To study this, a clone of QWOP game with keyboard, gamepad and motion control interfaces was developed for this study. The objective was to find out how choice of control interface can affect the controllability, playability and engagement of the game. The test was carried out with 18 participants in the Aalto university campus area. Each participant played 5 minutes with each interface and a questionnaire between and after the play sessions was carried out to provide data about the player experience.

The results suggest that controlling physically based characters is mentally demanding and the interface can hinder playability, engagement and controllability if implemented poorly. Users seemed to prefer clear and deterministic mapping between the inputs and interfaces where the characters were easier to keep stable, allowing the user to learn how to proceed in the game. Motion controllers combined with inverse kinematics control scheme seemed to be a promising way to manage the complexity of control. Special care should be put to designing the interface to ensure the intuitiveness of use. The study provides also insight to the techniques, issues and sources of engagement related to controlling physically based characters.

Keywords:	physically based animation, physics-based animation control, interaction techniques, character animation, game controllers, controllability, player engagement, qwop, awkward physics games
Language:	English

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Pelilaitteiden laskentateho on lisääntynyt ja fysikaalista simulaatiota hyödynnetään animoinnissa yhä enemmän. Fysikaalista simulaatiota on kuitenkin käytetty varsin harvoin suoraan pelaajien ohjaamien dynaamisten hahmojen animointiin menetelmään liittyvien ohjaushaasteiden vuoksi.

Tässä diplomityössä tutkittiin, liittyvätkö dynaamisen hahmon ohjattavuusongelmat hahmojen ohjaukseen kehitettyjen käyttöliittymien epäintuitiivisuuteen vai onko hahmojen suora ohjaaminen itsessään haastavaa. Fysikaalisesti mallinnetuissa räsynukkepeleissä hahmon suora ohjaaminen on tärkeä osa pelin peruspelimekaniikkaa. Tutkimalla näiden pelien pelattavuuteen ja kiehtovuuteen liittyviä tekijöitä, voisi selventää mitä asioita tulisi huomioida kehitettäessä käyttöliittymiä suoraan ohjattaville hahmoille. Tarkempaa tarkastelua varten työssä kehitettiin kopio QWOP-pelistä, johon toteutettiin käyttöliittymät näppäimistölle, peliohjaimelle ja liikeohjaimelle. Pelin avulla pyrittiin selvittämään, miten ohjaintyyppi vaikuttaa pelin ohjattavuuteen, pelattavuuteen ja kiehtovuuteen. Testi järjestettiin Aalto-yliopistossa ja testiin osallistui 18 koehenkilöä. Pelaajat pelasivat viisi minuuttia kutakin käyttöliittymäversiota ja sessioiden välissä kerättiin pelikokemukseen liittyvää dataa kyselyiden avulla.

Tutkimuksen tulokset osoittavat, että hahmon suora ohjaaminen on kognitiivisesti haastavaa ja ohjauskäyttöliittymän puutteellinen toteutus voi haitata ohjattavuutta, pelattavuutta ja pelin kiehtovuutta. Tutkimuksessa käyttäjät suosivat ohjaustapoja, joissa pelaajan teon ja hahmon liikkeen välinen yhteys oli helppo hahmottaa, ja joissa hahmon tasapainon ylläpitäminen ja pelissä eteneminen oli helpompaa. Ohjauslaitteesta riippumatta ohjaustavan intuitiivisuuteen tulisi kiinnittää erityistä huomiota. Liikeohjain yhdistettynä käänteiskinematiikkaan vaikuttaisi lupaavalta tavalta hallita ohjaamisen kompleksisuutta. Tutkimus tuo esille myös dynaamisen hahmon ohjaukseen liittyviä tekniikoita, ongelmia sekä pelin kiehtovuuteen vaikuttavia tekijöitä.

Asiasanat:	animaatio, fysikaalisen hahmon ohjaaminen, hahmon suoraohjaus, simulaatiopelit, peliohjaimet, ohjattavuus, pelattavuus, qwop
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Minna Turunen

Abbreviations and Acronyms

DOF	Degree of freedom
PD-controller	Proportional-derivate controller
IK	Inverse kinematics
PAD	Pleasure-arousal-dominance
SAM	Self-Assessment Manikin
GEQ	Game Engagement Questionnaire
SUS	System usability scale
SD	Standard deviation
M	Mean
UI	User interface
KD/LS	Kinematic-dynamic and literal-symbolic control space
PX	Player experience
NPC	Non-playable character
DPC games	Direct physics control games

Contents

Chapter 1

Introduction

The increase in the computational power in gaming platforms has led to a situation where physically based animations have become an accessible way of producing rich animated content. In games, physically based animation is mostly used in animating passive background elements, such as fluids, clothing and rag-dolls. For characters under players' direct control, kinematic non-physically based animation approaches are still the norm in most of the commercial games. [18]

There's one game type that embraces physically based character animation: awkward physics game genre. Possible alternative name for this game genre could be direct physics control games (DPC games). We chose the term awkward physics, because it relates more directly to the fact that the resulting movement in this in these games often looks awkward due to the difficulty level of both the game and the control scheme bordering absurdity. The awkward physics games don't have an official game genre name yet and they are often categorized under "simulation", "physics", "action", "humor" and "comedy" subcategories. These type of games can be considered to implement interactive animation control systems described by Laszlo et al [25] in game context, embracing instead of minimizing the difficulty of control.

The inclusion of a physically based directly controlled animated character is what separates the awkward physics genre from other simulation and physics driven games. The key characteristics that define the awkward physics game genre are:

1. Player controls a character or part of character whose movements are dynamically animated based on players direct input.

2. The player controlled character is affected by and/or affects the physics of the virtual world.

3. Core gameplay of the game revolves around mastering the control interface effectively to control the movements of said character.

With kinematically animated characters, actions such as jumping, running, walking and shooting are usually symbolically mapped to a single command with the input device. One key press or combination of key-presses triggers the action and the animation associated with the action. [18, 25, 27] In physically based character animation, instead of controlling the actions of the character, the player must directly manipulate the forces and torques inside said character, making complex tasks such as locomotion and balance a challenge on their own. [18]

This interesting premise of making even mundane tasks difficult is part of the charm of the games of this genre. Compared to many other games where the player takes the role of a highly competent and powerful protagonist [50], in an awkward physics game is the exact opposite - the character often appears very clumsy, knocking objects over and causing general destruction and mayhem. The struggle of the character becomes the struggle of the player, and character's success is directly related to the success of player mastering the control interface. This unpredictability in character control and the mischief caused by it may be one of the main sources of engagement playing this type of game.

A typical virtual character commonly used in video-games consists of more than 40 degrees of freedom (DOF) [27]. This makes building an interface for dynamically controlled character a challenging task - the interface must simplify the character movement to bring down the high number of variables to a manageable level while maintaining the nuances of the performance used to control the motion [25]. This interface to control dynamic motion can vary from symbolically mapped key-presses to literal movement control by motion capture and anything in between [27].

The controllability of dynamically driven animation is one of the key limitations that prevent dynamically driven character animation from becoming more prominent in commercial games [18]. It's hard to say, if this lack of controllability is caused by the lack of good control interface or if this natural cause of the complexity of controlling characters movements directly. Even awkward physics games can't directly provide an answer to this question because many of the interfaces developed for these games is usually deliberately less than intuitive.

1.1 Problem statement

The aim of this thesis is to study:

1. Sources of difficulty in controlling a physically based character.
2. Ways how an control interface can enhance or hinder controllability of physically based character.
3. How choice of character control interface relates to the playability and engagement of an awkward physics game.

This study aims to provide an answer to a question *whether the difficulty of controlling a dynamic character is mainly caused by its fundamental complexity or if this complexity is mainly caused by the use of unintuitive control schemes and interfaces.* In particular, we hypothesized that precise enough motion tracking could provide an easier way of controlling physically based characters, and if that were true, it would be interesting to study whether an awkward physics game would still be engaging.

Individual aspects of this thesis have been studied in previous works, but the connections of all these three aspects on dynamic character control have not yet been tested empirically.

To narrow down the scope of this study, and to study impacts of game controllers, we are going to approach aspects of controlling a dynamic character from the point of view of awkward physics games. Focusing on this particular game type is justified in a way that all these aspects are part of the core gameplay of the genre. Being a niche game genre, these types of games haven't been studied much before and trying to find out what makes dynamic character control engaging in this game type may provide good insight for developers of any game genre how direct control of dynamic character could be used to enrich the playability of their own games.

To answer the questions stated above, we chose to implement a test game that would allow to compare the effects of three different input devices and control schemes on controlling the same physics based game. Keyboard, gamepad and motion controller were chosen as input devices for the implementation. The test game for this study was modelled after QWOP - a flash game that may be the most prominent example of the awkward physics genre. In the game, the player controls the hip and knee joints of a 2D bipedal runner character with the goal of running as far as possible without falling down. Screenshot of the implemented test game can be seen in figure 1.1. The test data was planned to be gathered with 18 participants using both qualitative and quantitative research methods to collect data of how the different interfaces might be affecting the gameplay.

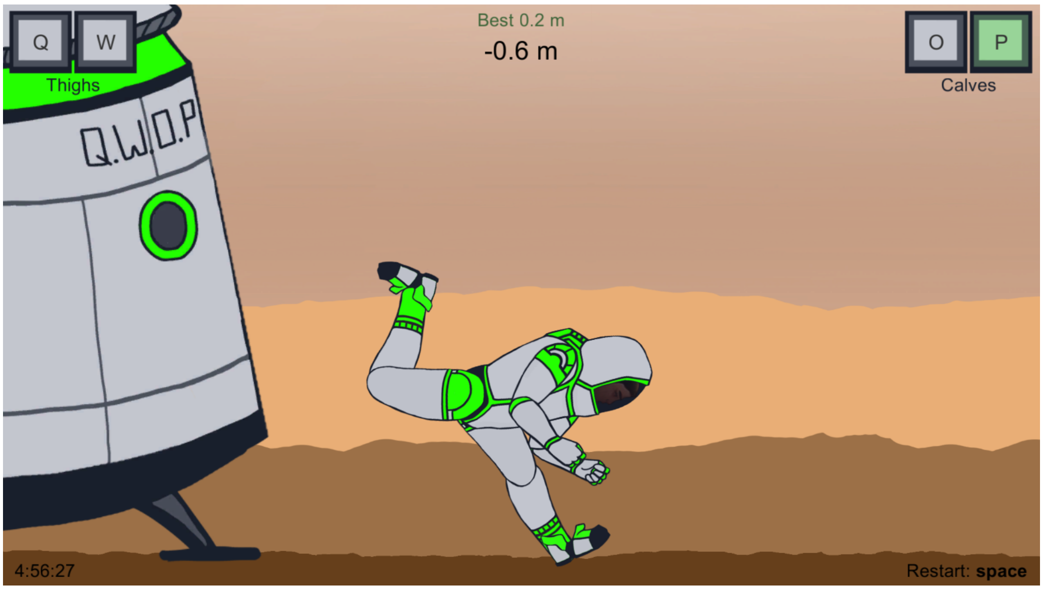


Figure 1.1: Keyboard version of the implemented test game: Q.W.O.P.

1.2 Structure of the thesis

We start by reviewing existing literature about the subject in chapter 2, focusing on questions of how natural control of human bodies differs from controlling a physically based character (section 2.1), how physically based characters are typically used in gaming (section 2.2), possible ways engagement can manifest in physics based character control (section 2.3), how choice of interface can affect character control (section 2.4) and how these principles have been used in existing awkward physics games (section 2.5). In chapter 3, the game implemented for this study is presented in more detail, and the data gathering tools used for this study are reviewed. The results gathered in the study are represented in chapter 4 and analysed in more detail in chapter 5. The conclusions and the answers presented in this study are presented in chapter 6.

Chapter 2

Background

2.1 Differences between human and character motion control

To better understand what makes controlling a dynamic physically based character difficult, we start out with how humans usually control movements of their own body. Controlling a body of a character is in many ways fundamentally different from controlling body of a person, and these problems have to be taken into account when designing an interface that allows player to dynamically control an character inside the game world. The first section offers a brief introduction to how human sensory-motor system works. In the second section, we tackle what difficulties the lack of this sensory-motor system causes to controlling a virtual character.

2.1.1 Natural human motion control

Controlling the performance of natural human movement is a complex mental process. It uses sensory information from both inside the body (proprioceptive channel) and outside the body (exteroceptive channel) as feedback to carefully fine-tune the movement produced by the muscle system to achieve a desired motion. [42] This process can be modeled as an closed-loop control model (see figure 2.1). In the model, to achieve a desired state of motion, the closed-loop system uses feedback from both proprioceptive and exteroceptive channels to calculate the current state of motion and the error between the current state and the desired state, and adjusts the current motion so that the movement would achieve the desired state in given time frame [42].

The big loop in the model that goes through all the stages of the closed-loop system corresponds to the conscious action. The model also includes

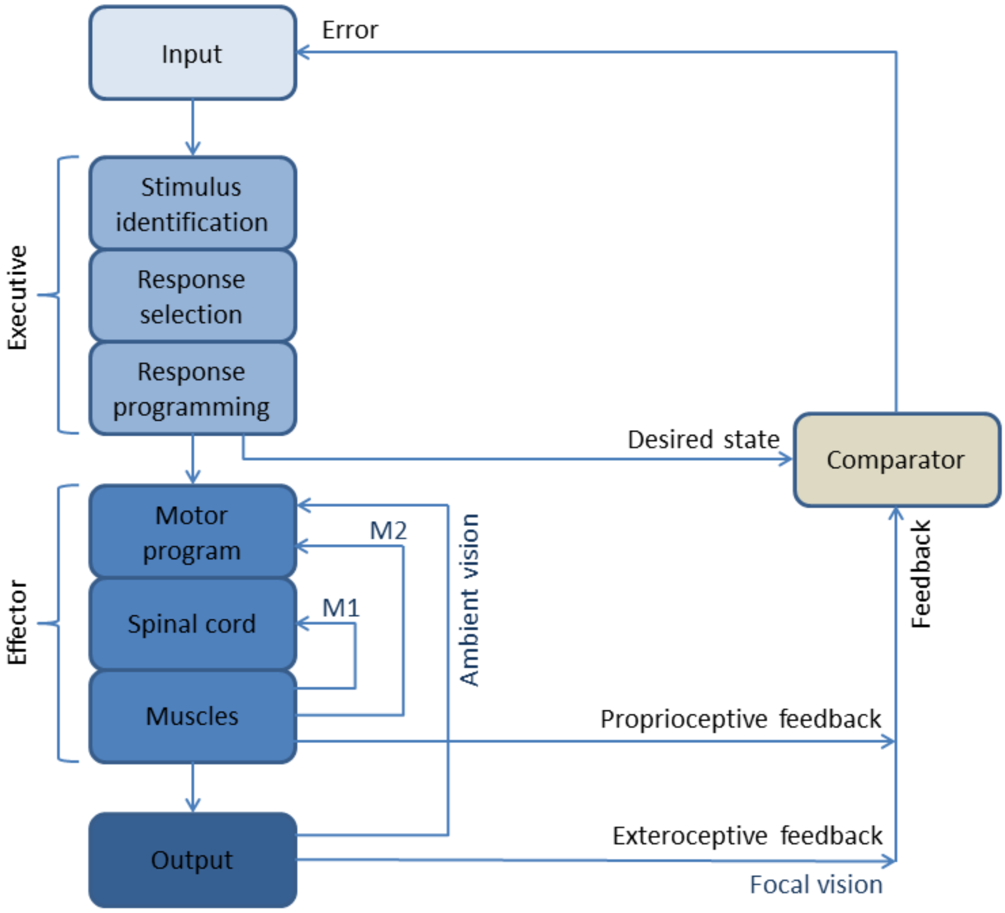


Figure 2.1: Conceptual model of movement control [42]; own depiction

various loops within the loop to regulate smaller and more automated parts of the motion. Each of these loops are different in that they rely on different sources of sensory information and use different parts of the nervous system to control the motion. The reaction time can vary greatly depending on which of these movement channels are used. Faster reaction time is achieved by bypassing, partially or fully, the conscious control state and using reflexive automated movements to maintain a continuous, balanced state of motion. The latency of M1 channel, which reacts to muscle stretching and correct errors within muscle to maintain current state, can be as fast as 30-50ms, which is considerably faster compared to 100-200ms latency of channels that require conscious motion control. [42] The different information channels, along with their latencies and what parts of the body they control, can be seen in table 2.1.

	Response type	Latency (ms)	Information	Area of control	Conscious control
Motion	M1 response	30-50	Muscle stretching	Same muscle	None
	M2 response	50-80	Forces, joints, orientation	Muscle groups	Intention may affect
	Reaction-time	120-180	Combined information	All muscles and longer-term control	Conscious
Visual	Ambient vision	100	Central and peripheral retina	Locational information in relation to self and environment. e.g. balance, direction, velocity, impact time.	None
	Focal vision	200	Central retina	Identifying objects	Conscious

Table 2.1: Reaction time latencies for different forms of motion control channels. [42]

Humans are visual animals, and visual information plays a big role in sensing and controlling motion. Visual sensory information can be divided into two types of information channels that are used to control movement - focal and ambient vision. The focal vision, used mainly for object identification, as well as audio use the slow exteroceptive feedback channel in the closed-loop motion control system. The ambient vision on the other hand, is important in detecting motion. [42] The processing of visual motion information starts on the retina, where the optical flow information across both central and peripheral areas in the retina are used to extract spatio-temporal event information about movements of objects in the world in relation to the motion of the observer. [4] This information can be linked directly back to the muscle system [42]. Perceiving motion is important to various locomotion tasks such as recognizing positions of objects in the environment, speed and velocity the objects are moving in relative to the observer, keeping balance and timing the contact between the observer and the objects moving in the environment [4, 42].

2.1.2 Challenges of disembodied motion control

The main difference between controlling a natural human movement and controlling a character on the screen is that in most of the times only visual and aural information can be used to provide feedback about the movements of the character. This could affect the player's ability to control a character in three ways.

Firstly, the reliance on aural and visual information cuts out most of the unconscious information channels used for fine-tuning and maintaining posture (M1, M2 and ambient vision) [42]. This means that the player must consciously try to control something that they would normally not have to control. Additionally, the conscious channels have much slower latency compared to the unconscious processes [42], meaning that even when the user observes an error in the posture that needs to be corrected, they can't react to the change as fast as they would when controlling their own bodies.

Secondly, the player may not get to use their ambient vision to the same degree as they would get to use when moving inside the natural world. The degree of how much they get to use the ambient channel might depend from game type (e.g. in first-person 3D game the visual information might be similar to the visual information that person gets while moving in real environment), but it is still movement in relation to the character instead of the observer itself, which may require additional mental processing. It is possible to overcome this problem with a fully immersive display using full field-of-view and natural head-tracked first person perspective. That being said, this type of interfaces are still very rarely used in games.

Thirdly, the set of movements required to control a character might fundamentally differ from the set of movements that are required to produce the motion. For example, the real walking motion has to be often replaced by walking in place, because the player can't necessary move in their gaming environment as freely as the character can in the virtual world [34]. This may create a jarring feeling because the body knows how the movement should feel like [36]. Because of all the information channels used for motion control, the motion can feel different to a person performing the motion even if one parameter is changed. For example, the movement feels different when you are lifting your own leg versus some other person lifting it for you because of the intention and procedural information associated with that motion. [42]

Information of how to perform the movements is mostly handled by the implicit or procedural parts of the long-term memory system. Information of how to perform an action is acquired by practise. When practised long enough, actions become automatic and reflex like and the person no-longer has to consciously pay effort to perform them. Unlike explicit or declarative memory, the information in the procedural memory is mainly controlled by unconscious processes, making verbally recalling and describing a learned action difficult. [24] Using this procedural information for something similar yet fundamentally different, may not transfer as well as explicit information. The player may be required to practise how to perform same movements on a different system all over again. Automatic recall of the original task may actually make the learning of the new task more difficult as the old information conflicts with the new one [24].

2.2 Role of physically based animation in games

Physics simulation is widely used in commercial games to create responsive animations that react realistically to the changes in the virtual environment. Typically, physically based animation is used to animate passive elements inside the virtual environment that aren't under player's direct control, such as fluids, clothing and rag-dolls. When animating a character under player's direct control however, kinematic approaches to animating the character are still the norm. [18]

In kinematic animation, the motion of the character is predefined either by recording it with motion capture or manually crafting it with keyframing. The right animation for each situation is selected using complex state machines, events and scripts. The limitation of using this method is that all the motions of the game character must come from the motion database. Creating a motion database that covers all the possible interactions that the game needs can be an expensive and time-consuming task. [18] With kinematic approaches, the system's ability to generate realistic and non-repetitive responsive animations to different events is restricted [18], and novel situations or unexpected changes in the physics environment might produce glitches or unnatural animation.

Physically based character animation offers an alternative solution to this problem. Instead of directly manipulating the motion trajectories of the characters, the motions can be simulated physically. With this approach, the ways the character can interact with the environment aren't restricted by the pre-recorded motion sets, and the character can produce physically accurate novel interactions with the game environment without additional motion data or scripting. [18]

A physics-based interactive character needs at least three components in order to function [18]:

1. Real-time physics simulation engine for handling the physics and interactions inside the virtual world.

2. Physics based character that can act in simulated environment. The character model itself needs at least:
   (a) A body to define geometry and distribution, usually built with rigid bodies.
   (b) Joints to control and limit the ways the body parts can move in relation to each others.
   (c) Actuators that can apply forces and torques to the rigid bodies and the connected joints.
3. Motion controller that can affect the movement of the physically based character.

All of these aspects are usually simplified from their real-life counterparts to allow simpler simulation. The appropriate choice of character model and control scheme depend on the motion controller strategy going to be used with said character model. The character model can vary from simple hinge joint constructs to complex muscle system simulations where even complex things like gait energy storing and joint padding can be simulated. In similar way the motion controllers can vary from simple joint-space motion controllers (calculation of joint torques based on kinematic target trajectories) to more sophisticated and automated control strategies (e.g. stimulus-response networks or constrained dynamics optimization). [18] In this thesis we focus mostly on the direct and local feedback control strategies, because they are at the moment the most common ways of controlling character motion in an awkward physics game environment.

The different dimensions that can be used to control a character as well as major challenges for dynamically animated character and ways to tackle these challenges are explored in the following sections.

2.2.1 Dimensions of character control

Designing interfaces for virtual characters interacting in physically simulated environment is not a trivial task. A typical virtual character can consist of more than 40 degrees of freedom (DOF). [27] Direct control of characters with limited number of DOFs is possible with practise, but with high number of DOFs controlling all of them individually is no-longer feasible because the cognitive load to keep track of all the variables individually becomes too demanding. [25]

The ways a character can be controlled in a game vary based on two dimensions: from literal to symbolic (LS) and from kinematic to dynamic

(KD) (see figure 2.2). The LS axis represents the directness of the mapping between input and the motion of the character, while the KD axis represents whether the motion is fully determined by prescribed parameters or if the motion of the character is affected by the physical interaction with the virtual environment. [27] For example, traditional gaming interfaces usually rely on prescripted motion with symbolic action mapping, where single key press or combination of inputs represent the whole action of an character. [25, 27]

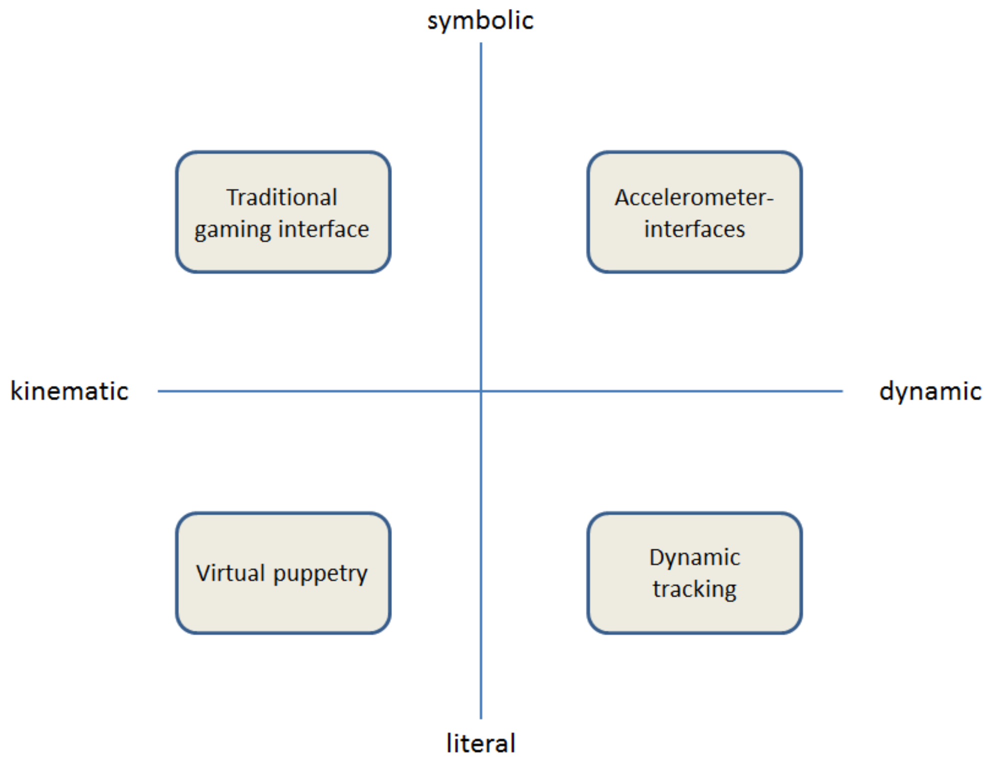


Figure 2.2: KD/LS control space for character animation [27]; own depiction

The awkward physics games fall on the dynamic end of the KD axis, but may vary a lot on the LS axis. On the literal end of the spectrum, the character is extremely sensitive to the performance of the player and mimics their entire pose. On the symbolic end of the spectrum, the control of the virtual character becomes increasingly symbolic and dissociated from the real-time performance allowing semantic mapping between the input device and the action of the character. [27]

The dynamic character animation can also vary on the degree of abstraction of how the inputs given by the user are used to control the actions of a character. The degree of abstraction can vary on [25]:

1. The number of body elements controlled by single input (joint, limb, inter-limb coordination, action sequences)

2. The time frame of action being controlled (instant action, action interval, sequence of intervals)

3. How much information is taken into account when calculating motion for the character (current state, previous states, possible future states)

The simplest way of controlling a character is to set the desired joint angles directly with an input device having equivalent degree of freedom. This form of control is limited only by the degree of which a person can learn to simultaneously manipulate a large number of DOF independently, as the character becomes more and more complex to control as the number of DOFs increases. [25] This way of control corresponds to the joint-level, instant action, and current state control on the dimensions of control abstraction scale.

The complexity of controlling a big number of DOFs can be limited by allowing coordination of multiple joints with a single input. One way to achieve this is set a target for a limb and use inverse kinematics (IK) to calculate the joint rotations needed to achieve the target pose. [25] IK typically needs to be coupled with a proportional-derivate controller (PD controller) or some other local feedback controller to allow the physically based character follow the instructions of the user while still staying true to the limitations of the virtual physics environment. [18, 25] This abstraction provides limb-level instant action control that allows previous or even possible future states taken into account while calculating the poses for the limbs.

The higher level of abstraction in the action control simplifies the process of controlling a physically based character, allowing the player to focus on higher level tasks and goals [25]. When taken one step futher, we get inverse dynamics, where forces and torques required to perform a motion (e.g. take a step) or even entire action sequence (e.g. walk here) can be calculated from an example set of prescripted or optimized motion parameters. [18] At the same time, the control may lose some of the stylistic quality of the player performance. It may also become more computationally demanding and more complex to implement as more actions are calculated and simulated for the player instead of the player having to control them directly. [18, 25] This level of control abstraction can modify inter-limb interactions or even whole action sequences. It can be used to control action sequences of any time interval (although, the phase of action may cause some delays to user input) and use both previous and predicted future states to help calculating the motions for the user.

2.2.2 Challenges of physically based character control

Controlling a character in virtual in environment is not trivial. There are some challenges that have prevented the physically based character animation becoming more popular in mainstream gaming.

The first issue is controllability. In physically based character, animation the pose and the movement of the character are a combination of both internal forces and torques affecting the character, as well as the forces imposed on the character by the virtual environment (e.g. collisions with objects or sudden impulses from hits). Because of this, even simple tasks like keeping balance or moving forward become challenges that either the player (or the system with higher level control strategies) has to tackle. Even simple tasks, such as switching between walking and running, become challenging as the player has to adjust their way of controlling the character to achieve the desired change in motion. [18]

The second issue arises from timing. The player has to time their actions in sync with the physics of the virtual world in order to keep balance, especially in the direct, joint level character control [25]. Because of the lack of normal bodily feedback (e.g. tactile feedback of feet hitting the ground) and reliance on visual feedback described in chapter 2.1, the reaction time the user can respond to a change in the characters state is much slower compared to similar reflex inside a human body. The simulation has to be carefully crafted so that it is fast enough to allow the natural rhythm of the movement but slow enough that the user can react fast enough to correct movement of the character when needed [25].

The third issue is believability of the animation. Even though the physically simulated character animations might be accurate inside the virtual world, it might lack stylistic quality that makes the motion seem real. [18] The believability of player's avatars motions in the virtual environment is big part of the quality of experience for the end users [27]. Humans are experts in interpreting human motion; any unnatural artifacts in the simulation or in how the avatar interacts with the virtual world may feel jarring and uncanny, possibly breaking the immersion of the game's virtual world. Even when direct manipulation of joints is used, the input device might not capture all subtle balance correction behaviour [18] that are necessary for making the animation look real. Applying style to the motion is not trivial, since they may disturb the basic tasks, such as keeping balance [18].

The fourth challenge is that physically based character animation is still a novel technology and lacks the many sophisticated tools and research that its kinematic counterparts have. This makes implementing a system that supports them a complex task. In addition to this, a physically based character needs more computational power to it's kinematic counterparts and some of the more sophisticated motion optimisation techniques are currently feasible only for off-line use. [18]

2.3 Game Engagement

One of the key reasons why people play games is the subjective experience of enjoyment and engagement that they offer [5]. This experience is a combination of player's sensations, thoughts, actions and meaning-making in the gameplay setting, which emerges from the unique interaction process between the game and it's player. Because of the player's active participation in the experience, the way the player experiences the game is never fully defined by the mechanics and elements embedded to the game alone. Player's active participation in the meaning making process is one of the reasons the experiences offered games are so powerful. [15] The fact that the game industry is one of the fastest growing leisure markets is a clear indicator of the games power to engage their players [5].

Despite the popularity of games, the engagement and the other terms related to the gameplay experience are tricky to define. Engagement, enjoyment, immersion, presence, flow, arousal and other terms associated with playing games are very similar terms but emphasise slightly different aspects of the subjective experience of playing games. [5]

One of the most influential theories used to explain the subjective experiences while playing games is the flow theory [5]. Flow can occur when a person is immersed in and deeply concentrated in doing an intrinsically motivated activity where the activity itself is rewarding. To achieve the state of flow, the challenges offered by the activity must stretch the current skills of a person in a way that the level of challenge and the skills of the person are in perfect balance. The state of being in flow is characterized by intense and focused concentration, merging of action and awareness, feelings of control, distorted sense of time and the loss of reflective self-consciousness. Feeling of flow can be a motivational factor as it encourages person to continue doing an activity that caused the flow state to occur and by doing so it helps to develop skills regarding it. The flow state is fragile - if the demands of the task are much lower than the skill required, the experience turns into boredom or apathy. If the demands of the task are too high the person is more likely to experience anxiety rather than flow. [31]

There are many aspects in games that support achieving flow state. The games usually involve challenging activity with clear goals that the player can complete with immediate feedback of how well the player is doing in the game. [32] On the other hand, the game engagement must not be confused with flow. Even though they both are characterised by the presence of strong positive emotions, flow is a stricter term requiring both high skill and high challenge to be present in order to occur. [51] Engagement and enjoyment can occur even in low challenge situations if the player's skill exceeds the skill level required by the game. Both the valence (enjoyability of the experience) and the intensity (immersiveness of the experience) of the player experience contribute to the feeling of flow (see figure 2.3). [30]

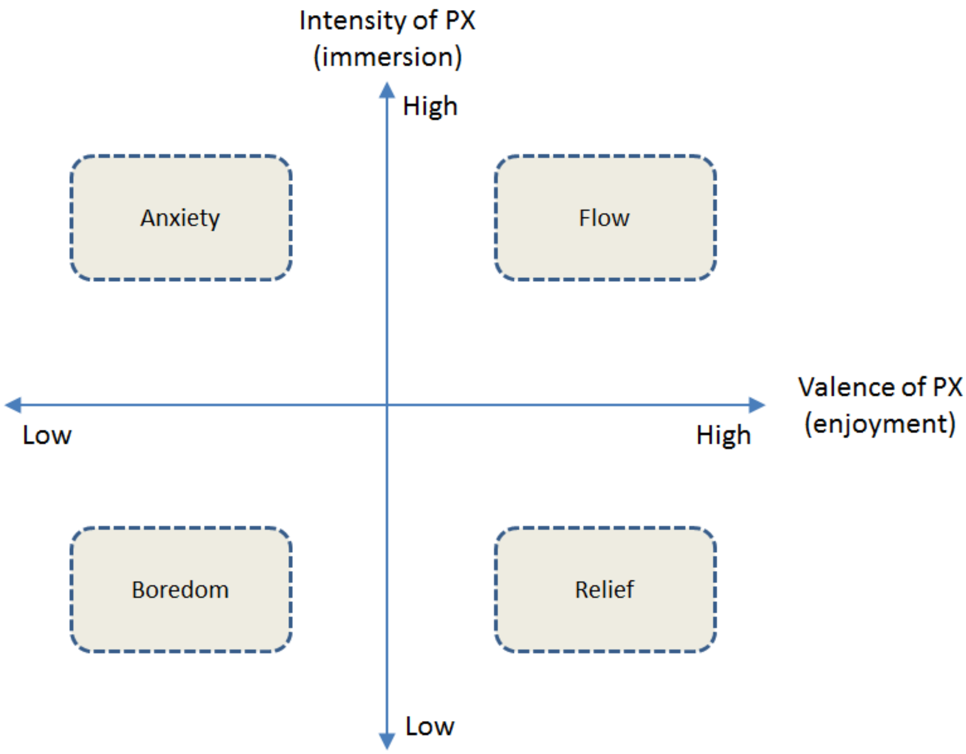


Figure 2.3: Valence (enjoyment) and intensity (immersion) of PX. [30]; own depiction

The valence of the player experience (PX) or the feelings of immersion, involvement or engagement typically are used to describe the extend of which player's attention is held by the challenges or by the feelings of presence in the game world. [30] The experience of immersion (see figure 2.4) consists of three elements: sensory-immersion (audio-visual execution that captures player's focus and provides steady stream of stimuli that overpowers the sensory information of the real world), challenge-based immersion (balance of player's motor and mental skills and the difficulty of tasks presented to them), and imaginative immersion (game's world, characters and story). The experience of immersion occurs when the game and the player interact with each others in a particular social and temporal context. [15]

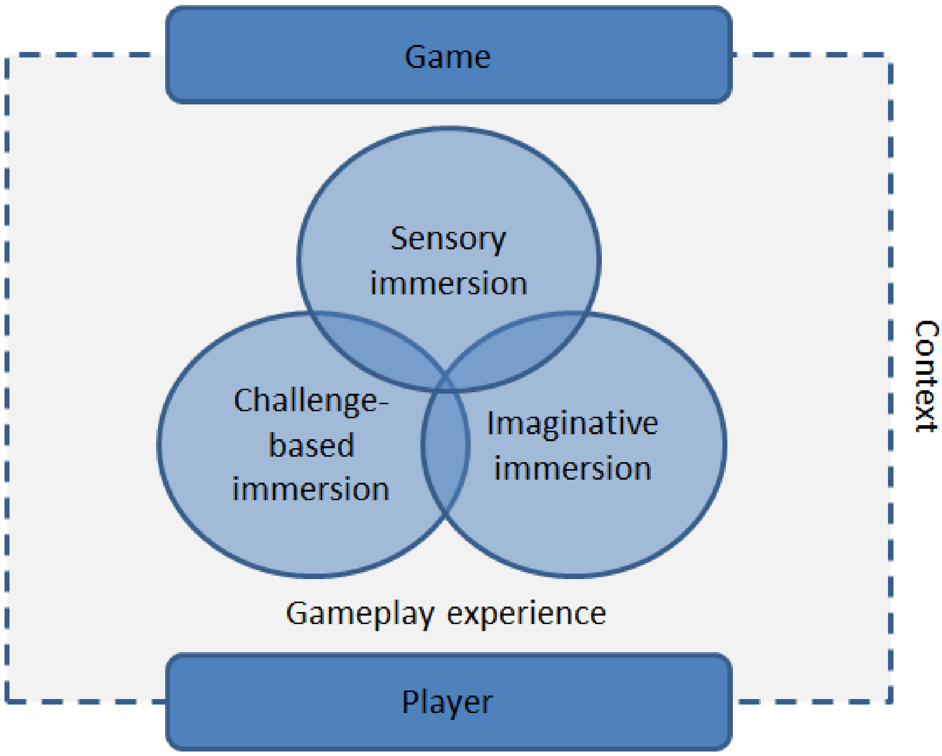


Figure 2.4: Key dimensions of immersion [15]; own depiction

Feeling of immersion can be facilitated or destroyed by the characteristics of the game. There are three levels of involvement which each contain an barrier that may hinder player's ability to achieve the level of involvement with the game (see figure 2.5). Removing these barrier allows the experience to occur, but does not guarantee it. [9]

The first level of involvement is engagement. An engaged user is interested in the game and wants to continue playing it. The factors that act as barrier for this level if immersion are access (player's game preferences

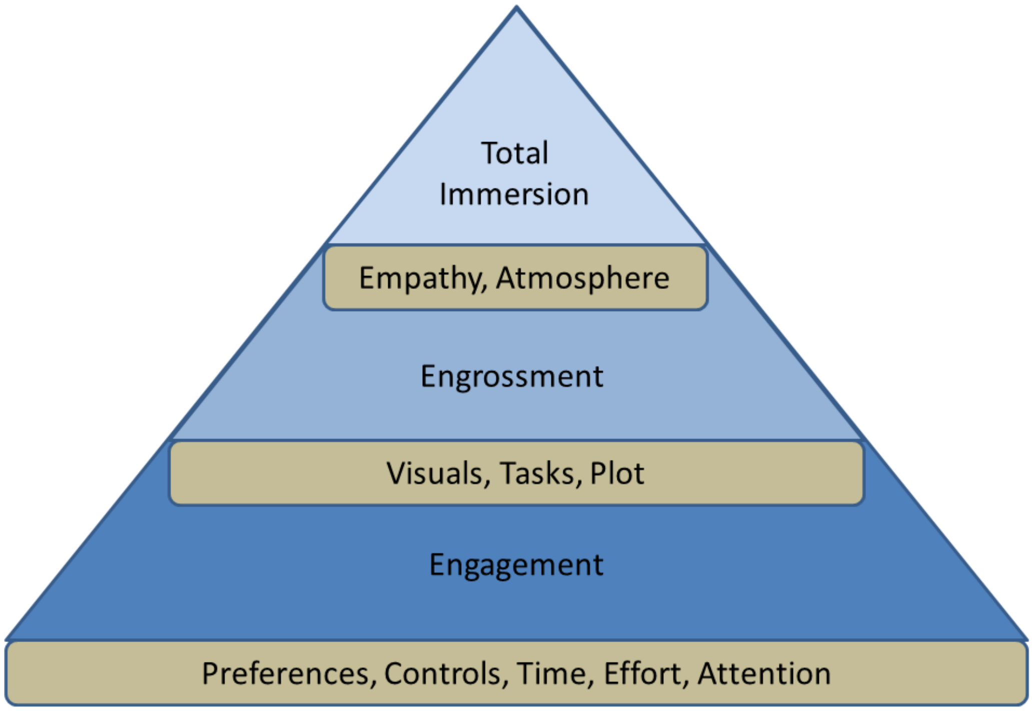


Figure 2.5: Three levels of immersion [9]; own depiction

and the approachability of the game's controls) and investment (time, effort and attention that the game requires in relation to the rewarding experiences that the game offers). [9]

The second level of involvement is engrossment. An engrossed player is emotionally highly invested in the game and the game world, and their sense of their surroundings and their self-awareness begins to blur. The construction of the game acts as barrier to this level. The features of the game, such as visual, tasks and plot of the game, must be put together in a way that the gamers' emotions are affected by the game. [9]

The third level of involvement is total immersion, where the player begins to feel like they are present in the game world with increasing detachment from the real world. The barriers to this level are empathy (ability to project themselves to the shoes of the protagonist) and atmosphere (visuals, plot and sounds that combine to support the overall tone of the game world). All the elements of the game have to work together for the player to maintain the highest level immersion. [9]

On the other hand, engagement can also be understood as an umbrella term for different aspects of game involvement as it contains immersion (player's feeling of being part of the game while still maintaining their awareness of their surroundings), presence (feeling of being present in the game world while still maintaining overall sense of consciousness), flow (altered mental state characterised by balance of skills, challenge, control, focus and motivation) and psychological absorption (altered state of consciousness in which thoughts, feelings, experiences and affects become less accessible to the consciousness). [7]

Being engaged is closely related to the topic of being involved in something. Being involved allows a person to say something of who they are and what they invest their energy in. To be engaged with something the following three conditions must be met. Firstly, the engagement occurs in interaction with the tool (game) and it's affordances and the affordances offered by the tool shape the experience of it's user. Secondly, the interaction must have an affective component and we continue to engage with something only if there's some kind of positive emotional experience involved (fun, pleasure, interesting, rewarding etc.). Thirdly, the experience must align with our sense of purpose and our identity and the actions we choose to engage with enforce this identity. [51]

While enjoyment is one of the key explanations of playing games, players also may experience negative emotions while playing games. Players may play games for negative reasons, such as escapism, avoiding boredom or depression. This has negative consequences for the players ability to regulate and control their gameplay. As with other highly enjoyable behaviours, the fine line between enjoyment and addiction is very thin and even players who are not addicts may show both harmonious and obsessive behaviour towards games. [5]

2.3.1 Role of difficulty in game engagement

In addition to enjoyment, challenge is also one of the main motivational factors why people choose to play games. Challenge satisfies the player's need for achievement or competence which both are important motivators for behaviour. [5]

Game difficulty can be defined by degree of cognitive an physical effort required to complete a task in the game. A task can be said to be difficult if the current level of skill that the player has doesn't match the skill level required to complete the task in the game successfully. The right level of difficulty is a key factor in making engaging experiences for the players. [37]

Because the skill level of the player tends to improve while playing the game, the difficulty of the game can't be static or the player's skills will surpass the difficult level offered, leading to boredom. Game difficulty however, should not just increase continuously, but it should follow an interest curve with ups and downs along the way to give a player to chance to rest before throwing the next difficulty spike at their direction. This helps the difficulty spikes to stand out more from the rest of the game-play experience making these moments more memorable. [37]

Designing correct interest curve for the game that maintains optimal challenge for both novice and expert players is an art form of it's own. Typically, developers try to avoid this problem by either letting the player choose from a set of predefined difficulty levels, or designing the game in a way that the game can adjust its difficulty on the fly based on the players skill level. [37] In competitive games, the feelings of enjoyment are the highest when the player is just a little bit ahead or little bit behind the other player. A bit higher score maximizes the feeling of competence while still maintaining suspense that the other player might catch up. A bit lower score is also enjoyable because of the high level of suspense caused by the likelihood of failure while still having a good chance to win the game. [1]

Difficulty is one of the reasons why people choose to play games. However, not every player seeks a same experience from the game. The reasons why people play games can be categorized into four categories [26]:

- Hard fun (challenge, strategy, problem solving and strategic thinking. Focus on progress and completing goals and winning the game. Associated with feelings of frustration or triumph).

- Easy fun (experiencing and exploring activities offered by the game. Focus on free-play and improvisation and feeling part of the game world. Associated with feelings of curiosity, mystery, wonder and awe).

- Altered state (enjoyment of the internal experiences and changes in players mental state. Focus on feeling something different during and after the play. Associated with playing games to relieve boredom or other negative mental state and the fun, excitement and relief gained from play).

- People factor (enjoyment from playing with others and playing to build social experiences. Focus on competition, teamwork and social bonding. Associated with feelings of pride for the accomplishments or gloating over misfortunes of others).

It is good to keep in mind that in the lab environment, the players tend to favour easier games than normal due to the fact that the lab context easily sets mental demand to perform well in the game, especially when engaging with the game for the first time. Suspense involves a chance of failure, which is not as enjoyable in a situation where the player is mentally compelled to perform well. [1]

2.3.2 Character behaviour and humor as source of game engagement

A player usually engages the game world through a component or components under their direct control, which usually manifests in a form of a character. Characters in the game can roughly be divided into character-of-self (character under player's direct control), character-of-system (non-player controllable characters who's behaviour is scripted as part of the gameplay) and character-of-other (characters in control of another player). Identification with the character-of-self or avatar can enhance or distract the immersion with the game world. [23, p. 45-92] The avatar is a player's representation in the game world and through the identification with the character, the player can temporarily live the life of the character [13].

That being said, the characters aren't always just plank slates for the players to project their identities on. The characters and the character designs can also be a major source of humor and enjoyment in gaming. The humor may come from their appearance, speech, action, interactions or withing the gameplay mechanics. When done right, humor and comical characters can increase the games appeal in the eyes of the players. [13]

Humor comes typically in three different forms: superiority (laughter at the expense of other, mockery ridicule and malice), relief (laughter to relieve tension, stress or suppressed emotion) and incongruity (laughter to unexpected, surprising or bizarre turn of events). [13, 14, 49] The humor manifests in games in three main channels: game-to-player (scripted and planned humorous content built in the game), player-to-player (spontaneous humor created in the context of play, shared with other players) and player-to-game (humorous playing performance that goes beyond the scripted content of the game). [14] Both the player and the game can participate as active participants in creative play, and neither the designers of the game nor the player can fully predict the results of this play. The player tries to exploit the game content with all it's flaws and game mechanics at their disposal to create absurd and incongruous moments for enjoyment of themselves and for others. [49] The humor is created through player's agency allowing the player to create comedic moments by distorting the game's rules, messing with the setting or experimenting with the mechanics offered by the game. [14]

The humor in awkward physics games comes in two main forms: through the character and through the gameplay mechanics associated with said character. In many games, the protagonist of the game are built on the power fantasy of competence and skill, which allows the player to briefly take a role of a character who is highly competent in areas the player is often not. Sometimes, the heroes are even competent on areas that the user is not, causing special requirements for the game interface so that the affordances and signifiers that the avatar would know are visualized to the player in recognizable way (e.g. red objects in Mirror's Edge to signify possible parkour run paths). [50].

In awkward physics games, this is not the case. In these type of games, the player typically takes role of an character whose physical capabilities are significantly lower than those of the player. The game mechanics of this game type are often built around with the idea of simulating situations of slapstick and humor to produce visual comedy [14] and the character's ability to interact with the game world may solely depend on the player's skill and competence with the character control interface. The character may be designed to be a lovable loser - a character marked by their incompetence and their habit of creating havoc where ever they go and somehow, despite all their flaws, still try to struggle towards completing their goals even if their success is caused entirely by accident. [13]

This type of character has to be built with care. The player tends to laugh at the character instead of identifying with the character and when built incorrectly, it may risk annoying or even alienating the player from the game world. The struggles of the avatar are the struggles of the player, and if the character becomes an obstacle that prevents the player from proceeding with the game, they may come off as frustrating instead of fun, and this risks alienating the player from the game world. For this reason, the lovable losers are more often used as NPCs (non-playable characters) instead of protagonists. [13]

The lovable loser type of characters can be quite powerful when their clumsiness is used in terms of gameplay possibility [13] The mechanics of the entire game can be built around with the idea of simulating situations of slapstick and possible sources of visual comedy and depending from the player this potential cause of physical mayhem can either be minimized or harnessed to it's full potential [14]. The player remains in agency over the slapstick caused by the character, which is different from most games where the slapstick may rely more on the ragdoll physics engine and coordinated loss of control over their avatars [49]. The struggle of the character becomes the struggle of the player and as the character fails or succeeds in their quest, so does the player. The players can laugh at the the mayhem caused by the character and feel the success when they finally manage to complete their seemingly impossible task.

2.4 Input device differences in terms of engagement and dynamic character control

The game interface (UI) has an important role in digital games. Without direct physical access, the interface is the only channel the player can use to affect and get information from the current state of the game. The interface thus contains all the parts of the game that the user can either use to get information from (e.g. the monitor and the game view) or to interact with (e.g. input device used to control the game). The interface of the game is an integral part of the gameplay experience and mastering it is just one of the many challenges that the player needs to face in order to learn to play the game. [23, p. 45-92] Usability of a game can be defined as degree to witch a player is able to learn, control and understand the game and the game interface [35].

The requirements for designing an interface for a game are different from the interface designed for traditional desktop interfaces. Visual clarity and consistency are just as important in gaming UI as they are in traditional interface design. The main difference is that in games, making errors and trying to figure out what to do can be part of the challenge of the game. [35] Everything in the game, including the game mechanics, have to be signaled to the player through the interface without breaking the immersion of the player or reducing the optimal level of challenge. The interactable parts of the game have to be signaled to the player using common knowledge or visualizing the knowledge the player might not know through the interface. If not done correctly, hidden affordances (interactable content not visible to the player) or false signifiers (content that looks interactable but is not) might confuse or mislead the player and possibly cause a break of immersion. [50] Common usability issues encountered in gaming that are related to the game interface include unpredictable or inconsistent responses to user's actions, unnatural input schemes, oversensitive, unnatural or unresponsive controls, over-long command sequences or steep learning curve and cluttered or hard to interpret UI. [35]

When choosing a control interface, the intuitiveness of the controls is one of the main factors to consider. Intuitiveness can be defined as an end result of a cognitive process that tries to match current stimuli with a store of pre-existing knowledge base build up through time with similar situations. No device or interface is intuitive by default, but the processing required by the interface can be similar enough that the correct action needed to perform the right action with the interface is selected subconsciously rather than based on analytical processing, leading to improved response time and accuracy when using the interface. [29]

Usually, more naturally mapped gaming controllers allow players to access their mental models of real-world behaviour faster, leading to more accurate and available information of how to interact with similar situation in the virtual world. Input mapping refers to a manner in which the actions with the input device are connected to the changes inside the virtual environment. It can range from arbitrary (unrelated to the function performed) to natural (related to the function performed). [45] Human perceptual and motor systems are optimized for real-life interactions, meaning that virtual controls that mimic the natural motions of the human body should feel more natural to use and bring heightened feelings of presence and flow. [29, 45] It's also worth noting that the input controls that the player is used to use to play a game may also effect how well another controller can be used to play a game - a switch from platform the players are used to play the game to another makes learning the other platform slightly more difficult even if the overall play experience may stay the same. [19]

Different game control interfaces have been classified by the amount of body movement they require for interaction as well as the type of mapping used in the interface (e.g. natural/realistic versus non-natural/symbolic) [28] The different input devices can be categorized into four categories based on how directly the action with the input device and the action in the virtual world are mapped: directional (correspondence between the direction of the physical input and the virtual result), kinetic (natural body movements captured and translated into equivalent actions in the game without the tangible component), incomplete tangible (physical input device that partly resembles the form and function of the equivalent virtual object) and realistic tangible (physical input device looks and feels and responds like the virtual object in the real world). [45] In this study, we focus mostly on the directionally and kinematically mapped controls since providing tangible feedback of the dynamic character interactions with the virtual world in a study topic of its own.

In physics-based character control, the input device used to control the character needs special attention when building interface for them. Physically based characters usually contain more degrees of freedom than what the input device can control directly [44] so any problems with the way the inputs are mapped to the character may hinder the controllability of the character.

In the following sections we go through several input device types and try to analyse how each of the can be used to control a physically based character and what benefits and issues using each input type might offer.

2.4.1 Keyboard interfaces

Keyboard input consists of the keyboard or button based devices offering an array of keys that act as mechanical levers or switches. Input device usually contains a fixed number of buttons that the game designer can choose to map to the actions inside the game as they feel appropriate. All the keys of the input device don't need to be mapped to build a game interface.

The main benefit of using keyboard interfaces to control actions of an dynamically animated character is that they allow arbitrary number of action semantics from any level of abstraction to be mapped to any of the keys of the input device [25]. A single key or keystroke either alone or in various combinations can be used. The keys can be used both as direct control actions as well as meta-actions to modify parameters related to the simulation or the control interface. This allows an instant access to a large selection of actions that can be used in either separately or in unison. A single key press defines "when" to perform an action and also "what" action to perform. [25]

The downside of using this form of input is that very complex mappings with high number of control keys can be hard to learn and memorize. Because the buttons are abstract and arbitrary representations of action, the user has to learn what each button means in terms of character motion [45]. Mappings built using keyboard interface are always un-natural, symbolic and arbitrary. [29]

2.4.2 Analog interfaces

Analog input offers continuous level of signal that can vary on a given scale. The benefit of using an analog input device is that it offers one to multidimensional input that can vary freely around it's center point. Typical devices used in gaming to give analog input are mouse, joysticks or gamepad control sticks.

Analog controls are especially suited for direct mapping, since they offer possibility of adjusting the state of an DOF with same degree of accuracy as the input device can offer. If the input device corresponds to the same number of DOFs as the character being controlled, the user can technically control all the aspects of the character performance simultaneously. It defines "when", "what" and "how much" of an action needs to be performed. [25] Mappings built with an analog interface are symbolic and unnatural, but the action done with the analog input can be directionally mapped to match the action inside the virtual world. [29]

The disadvantage of using analog input is that the analog signal tends to contain noise that needs to be clamped or filtered before using it as an input signal. Physically based characters are also generally regarded to be more difficult to control with traditional joystick interface because physics-based character can't necessarily response to the command instantaneously like with kinematically controlled character [44]. The delay usually feels more intuitive with the motion based interfaces, because the user can understand better the delays in the action when comparing it to the similar motion they are simultaneously performing. [44]

2.4.3 Motion interfaces

Motion controls are performance based input devices [44] meant to capture the natural movements of the user. Motion input devices currently available to games can be roughly divided into two categories: motion controllers that use a accelerometer or magnet based input device (e.g. Wii Remote, PlayStation Move, Razer Hydra) and motion controllers that use video input and infrared depth sensors to calculate the full-body motions of the end user (e.g. Kinect).

Motion capture devices show a good potential for providing a feasible way to reduce the complexity required to control a physically based character. [18] Motion control offers a player a chance to bypass the expertise requirements usually demanded to execute challenging virtual control actions with traditional interfaces by offering less abstraction between the task in the virtual world and the player action required to perform the same action. [29] For tracking purposes, they allow simultaneously capturing the target positions and target velocities of the limbs as well as the natural posture and rhythm associated with them [18]. The inputs with a motion controller can be symbolically or naturally mapped. If natural mapping is used it can be either directional or kinematic depending on the type of motion controller and mapping used to control the character inside the virtual environment. [29]

The body movements used when using a motion control device can be divided into five categories [2]:

- *Task-control body movements*. Focuses on maximum performance with the game. Movements are efficient and precisely aimed and usually recognized by the game interface (e.g. precisely timed wrist flick when using a Wiimote). Related to the hard-fun play style.

- *Task-facilitating body movements.* Conscious and unconscious control activities that benefit the cognitive processes required to play the game well (e.g. tapping the foot in the rhythm when playing a music oriented game). They occur with more skilled players only when the performance gain of the movement overcomes the cost of performing it. Usually not recognized as input by the game interface.

- *Role-related body movements.* Related to role adopted by the player in the game scenario. Associated with high levels of engagement and feelings of presence in the game world. The game interface may not recognize this sort of input and sometimes it may even hinder the game performance (e.g. acting like rock star on stage while playing Guitar Hero). More role-related controllers may encourage role-play related movements. Related to the easy-fun play style.

- *Social behaviour related body movements.* Movements related to facilitating and supporting the interactions between players (e.g. attracting attention, gestures of empathy, etc.). Focus on building the relationships between the players. Not usually recognized by the game interface.

- *Affective expression related movements.* Movements related to the player's current state of mind (e.g. frustration, boredom or triumph). Usually not recognized by the game interface.

The movements selected to use to control the game as well as the degree of freedom on movement offered by the controller have an effect on how the user will engage with the game and the difficulty level and the inputs used to control the game should be designed accordingly. [2]

In addition to benefits, using a motion controller as control type to control a dynamically animated character also provides some challenges that the game developers need to tackle in order to use this type of input in their game. Based on earlier studies, we can divide the challenges roughly into five categories:

1. Challenges caused by the discoverability of the control mapping.

2. Challenge caused by lack of fine detail in movement control.

3. Challenges caused by proprioceptive feedback and mismatch of movement between the virtual world and the physical world.

4. Challenges caused by bodily exertion.

5. Challenges caused by the controller or the lack of controller.

The first challenge is that motion controllers and especially full-body motion controller allow the player to select their movements from wider range of input than the traditional input devices. The controls of motion control are not constrained leading to situations where it's unclear for the player which of their actions are mapped to the movements of the virtual character and which are not. [34]. The interaction model used to control the character needs to be carefully designed based on the movements that the users are more likely to use with the interface. [2, 10] Part of the problem with designing such interaction lies in the separation between the locus of interaction (the body) and the focus of interaction (the screen). The user needs to learn how to map their movements to the movements on the screen, and figure out which of their movements might be relevant, and what the relevant movements might do in the context of the virtual world. [10] The game may present the player new experiences and novel situations to which the user might not know what action they should take, increasing the challenge of designing gesture set to be used in those situations. [34]

The second challenge is related to the the fact that even though the motion capture devices allow capturing the basic performance of the player they don't necessary manage to capture all the subtle balance correction behaviour required in natural movement. The forces of the virtual world also might not match the world present in the physical world (e.g. friction, tissue deformation, joint compliances). When used for physically based character control, this means that the movements are underactuated, and if the small errors in the posture are allowed to accumulate, it will eventually lead to the situation where the virtual character loses it's balance. [18] Input device may also include a lot of jitter in their capture method making gestures requiring more nuanced control, such as grabbing an object, difficult without helping the indented motion with more sophisticated motion control algorithms. [27]

The third challenge is related to the fact that the simulated character is never completely identical to the performing actor. Typically, the player needs to perform the movements in limited amount of space while keeping their gaze towards the monitor. [34] The movement may have to be replaced with similar movement that fits into the limited space (e.g. walking or running in place instead of physically walking around) or replaced with similar or symbolic gesture if the motion can't be performed in the play location (e.g. climbing monkey bars) or if the motion is dangerous for the player to perform (e.g. wall run). [27, 34] Some motions might not even have their real life counterpart (e.g. casting a spell). [34] This means that the gestures used to control character movement may be different from the gestures that the virtual character performs on screen and the performance of the player can't necessary be fully mapped to the performance of the virtual character on screen. Disappearances between posture of the virtual character and the user can also be caused in situations where the virtual character reacts to the physical event in the virtual world not present in the real world (e.g. the character is suddenly hit by a boulder). [27]

The differences may cause a situation where the proprioceptive feedback (sensory input from joints and muscles inside the human body) that the user is getting from their body doesn't necessarily match the movement of the character on screen, causing a mismatch that may break the suspension of disbelief. Simulating movement with other parts of the body may cause similar effect too, because walking with hands doesn't feel the same as walking with the feet. The interface should be crafted carefully so that the movement of the character matches the movements of the player as much as possible. [2] Choosing just the most natural option is not enough because the designers should also keep in mind what feels fun to perform physically so that use of the motion input interface itself becomes engaging. [36]

The fourth challenge lies in the fact that motion control is physically more tiring than their traditional counterparts. The fitness and the energy level of the user can become an issue if the interface isn't designed to keep this in mind. It may even cause ergonomic issues and possible injuries if the interface encourages users to seek workarounds around the motions intended to use with the interface to perform better in the game. [2] The physical effort required by the interface can be rewarding on it's own, and if the exertion required by the interface is coupled right with the game-elements, they can encourage the user to move more and develop their physical skills while playing the game. This however, means that the game has to balance the game in terms of fitness as well as skill and challenge dimensions, making designing a suitable game more difficult. Both too much and too little physical exertion can be detrimental for the player. [32]

The fifth challenge is related to the controller (or the lack of it) when using a motion control input. The controller can have an huge impact on game engagement in terms of what movements can be used for control, how much freedom of movement the user has, what level of accuracy the controller allows and how much it supports different playing styles and types of fun. More inaccurate controllers are more prone to error, but may support wider range of play compared to more accurate ones. [2] Tools (and controllers) can be seen as extension of self - disappearing in the usage and allowing the user to focus on the action instead of the tool used to perform the action. With full body-motion, the body itself becomes this tool and the performance differences between the real-world and the virtual world become more jarring.

This should be taken into a consideration when designing an interface for motion device without a controller. [36]

2.5 Examples of awkward physics games

This section lists some games as an example of games that belong to the awkward physics game genre. We briefly describe each of these games and analyze how simulated physically based characters and their control mechanics are used inside the game and how the game engages their players.

All the example games presented here used either keyboard or gamepad based input. Some of them supported even alternative input types (only one repented here if multiple). None of the games represented here had motion controller implemented as possible input device.

2.5.1 I Am Bread

I am bread [48] (see figure 2.6(e)) is the newest example used in this study, having finished its early access state at the time of this writing. In the game, the player controls a slice of bread trying to toast itself. The game uses simple household environment, where the player tries to find sources of heat and taste while avoiding contamination from ground or inedible materials. The toast is controlled by grabbing unto a surface with one of the corners of the bread slice using game-controller RB, RT, LB and LT keys (each controlling one corner of the character). The slice can then be panned and rotated using the analog sticks.

The movements of the character as well as it's havoc to the surroundings are animated dynamically. Simplicity of the character and limited number of control points allows even complex actions to be performed inside the game while still keeping the controls manageable. The engagement of the game comes from mastering the controls. In the first levels the challenge is simply moving around, but the stunts that the player is expected to perform with the character become progressively more difficult. The comedy of the game comes from the absurdness of making a simple slice of bread perform incredibly hard tasks.

2.5.2 Surgeon Simulator

In Surgeon Simulator [47] (see figure 2.6(d)) the player takes control of the left hand of a surgeon trying to do various operations, like heart transplants or brain surgery, for patients on the surgery table. The hand is controlled by using keyboard keys representing each of the surgeons fingers (A,W,E,R and space) to flex the fingers individually, and the mouse keys and mouse movements to move and rotate the hand. The objective of the game is to perform the operation as quickly as possible in a way that the patient loses the least amount of blood. The player can grab, move-around and use various objects and organs inside the game to do the surgery as they please. The game uses its difficult controls for comedic value as the surgeon's slip ups and very unorthodox procedures (accidental or purposeful) cause havoc in the operation room, often ending up killing the patient.

2.5.3 Toribash

Toribash [43] (see figure 2.6(b)) is a fighting game where player defines the characters motions by selecting individually, with mouse clicks, which muscle to extend, contract, hold or relax for each small time step. The aim of the game is to deal as much damage to the other player while avoiding taking damage from the other player themselves. The player is free to spend as much time fine tuning the pose for the time step. The possible outcome of the time step if the player doesn't change the muscles in the next time step are simulated using a short ghost preview animation. When the player is pleased with the configuration, they can advance to the next time step and adjust the configuration in the next time step.

The game engagement lies in mastering how each muscle configuration affects the movement and balance of the character as well as to develop strategies to counter the possible moves of the opposing player. With practise the player becomes more and more skilled in using the character and can perform more difficult and impressive looking stunts with them.

2.5.4 Octodad

Octodad [52] (see figure 2.6(c)) is a third person adventure game, where the player takes controls of an octopus masquerading as a human and has to perform various household chores and tasks while trying to keep his nature hidden. The player swaps between controlling either the legs or the hands of the character. In feet mode, the player uses the mouse to control the feet of the character - pressing left or right mouse button raises the foot of the ground and while the button is held down the feet follows the movements of the mouse until the key is released. In hand mode, the player uses the mouse to move the character's hand around and panning and grabbing objects is handled with the left and right mouse keys.

The difficulty of the control scheme is played for laughs as the character struggles even with simplest and most mundane task become almost impossible to perform without creating a mess (e.g. walking or picking up food from the fridge). The character designs, the story and the setting support the mechanics and the humorous tone of the game.

2.5.5 Trials Evolution

In Trials Evolution [39] (see figure 2.6(g)), the player controls a motorcycle driver performing various difficult tricks on a stunt track. In the game, the player uses the controller buttons as well as the analog sticks to control the speed of the bicker as well as to move the center of mass of the bicker forward and backwards. The game is extremely difficult and skill based, with high emphasis on learning how to master the controls to complete the tricks the track needs the racer to perform, using as little time as possible. Each time the player fails to perform the task, the player is reset back to the last checkpoint. These checkpoints are frequent to avoid player getting too frustrated with constant failure while they are still learning how to play the game.

Trials acts as example of an different kind of awkward physics game. The controls of the game are abstracted and simplified in a way that the game doesn't quite feel like an awkward game anymore. The controls of the game are very precise and proceeding in the game is very strongly defined by the players skills - the more skilled the player is in controlling the interface, the more impressive stunts the character is able to make on screen. This strong linking of character's and player's performance may be part of the commercial success of the game. The game was added to the list to provide an counter example of an awkward physics game where the movements of the character are physically based, but the interface and the character itself aren't that awkward.

2.5.6 Realistic Summer Sports Simulator

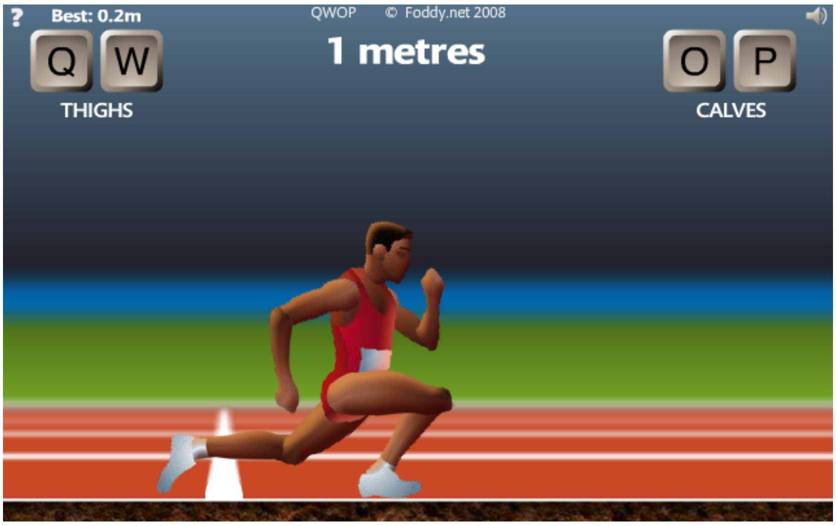
Realistic Summer Sports Simulator [46] (see figure 2.6(d)) is one of the simplest game chosen here as example. It's 2D sprite based game, that contains number of mini-games depicting various sports from swimming in a pool to riding a horse. Each mini-game contains a controllable object (e.g. swimmer) that the player can move around by quickly grabbing and releasing the object with the mouse, applying a spring force to the object. To be successful in the game, the player must maintain right speed and velocity for the object controlled and know what movement strategy to use in each mini-game. The engagement of the game comes from figuring out what to do in each mini-game. Both failing and succeeding in these games can lead to surprising situations that cause humor inside the game (e.g. gymnastic falling over after being done with their stunts or horse rider knocking over all the obstacles).

2.5.7 QWOP

QWOP [17] (see figure 2.6(a)) is a popular Flash game developed by Bennett Foddy and available to play on his website. In QWOP, the player controls a sprinter character in physically simulated 100-meter dash using 4 keyboard keys (Q,W,O and P). To win the game, player has to successfully reach the 100-meter mark. The player loses the game if runner's head or one of his hands touched the ground at any point during the play. [38]

The game is famous for being notoriously difficult, because of two main factors: it's control scheme and it's ragdoll engine. To run in QWOP, the player has to rethink of task of running while relying only on visual feedback. [38]

The keys used to play the game are also quite unintuitive. All four keys have an effect of both runners feet at the same time. Q and W control the thighs of the runner, moving them inward or outward, while O and P move the calves inward and outward respectively. Pressing QW or OP at the same time defaults to pressing only Q or O. One effective way to play QWOP is to use two key combinations: pressing QP for the left stride and WO for the right stride. [3] The character is animated procedurally based on physical movement of rigid bodies that are connected to together by joints. Any change in the runners legs has huge impact on the overall movement and it's very easy to sent the character falling over, since the game is very unforgiving to imprecise and poorly-timed movements. [38] Character moves relatively slowly, giving user some time to react, but because of the unintuitive controls, choosing right movement to correct falling process is often very difficult and requires lot of practise to master.



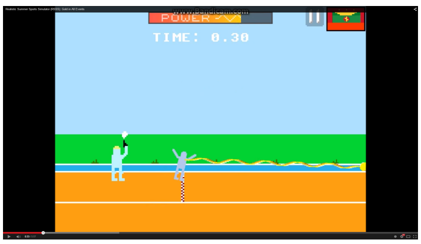
(a) QWOP (Foddy, B., 2008)

(b) Toribash (Söderström, H., 2010)

(c) Octodad (DePaul University, 2010)

(d) Surgeon Simulator (Bossa Studios, 2013)

(e) I Am Bread (Bossa Studios, 2014)



(f) Realistic Summer Sports Simulator (Smith, J., 2012)

(g) Trials Evolution (RedLynx, 2012)

Figure 2.6: Awkward physics game examples

Chapter 3

Methods

To have full access to all the variables affecting a dynamic character, we chose to implement a game from awkward game type for this study. In awkward game genre, controlling the character is directly linked to the gameplay experience and if all the other game variables are kept the same, any differences in the gameplay experience should be caused by the chosen control scheme. To study this, the popular flash game QWOP was chosen for it's relative simplicity and for being notoriously difficult to learn to control. For this study, we implemented a clone of the game from scratch with three different control schemes using three different controller types.

Information about the gameplay differences caused by the control schemes could be gathered with in game statistics. More subjective parts of the experience, like overall emotional state during the play, engagement and interface usability needed additional methods. Validated and widely used standard questionnaires developed for these purposes were chosen to obtain comparable information of these aspects of the experience. In addition to this, general information like player's controller preferences and average gaming time per week would be gathered.

The plan for the test arrangement was to let players to play the game with each controller type for 5 minutes (long time for a very difficult and frustrating game like QWOP) and gather before, after and in-between the game sessions the other data needed for the study with questionnaires. The test was designed in a way that the overall length for the examination for one test subject would be about half and hour.

Development of the selected awkward physics game and used data collection methods are explained in more detail in the following sections.

3.1 Q.W.O.P - building interfaces for physically based character

QWOP (described in more detail in section 2.5.7) was chosen as example game for this study, because the dynamic character as well as the game itself is relatively simple - you only control feet of a runner character and the only objective in the game is to try to move forward using the control scheme given. Controlling of the runner character is therefore directly linked to the playability of the game.

For the game used for the test, the objective of the game was switched from running 100m to try to explore as much ground as possible before the timer runs out (5 min). The 5 minute time limit was chosen to give the users enough time to get used to the controls and to get enough play data for comparison while keeping the total duration of the examination bearable.

The theme of the game was swapped from Olympics to Mars expedition to separate the study game from the original one. Having trouble with walking on a foreign planet after a long ride in zero gravity was a good allegory to the likely behaviour of the game character, as well as an tip of the hat to the humorous tone of the original game. Otherwise, the overall tone and feel of the game was kept as close to the original as possible.

As the objective of the game was to walk as far as possible, we decided to include a best distance meter to the UI that would be always visible to the players and updated every time the user made a little bit further into the game. The player was allowed to use whatever movement method they could come up with to move forward as long as the helmet of the character would not hit the ground. Players were also given an option to reset the level anytime they wanted, giving player a quick way to recover from mistakes and iterate their walk strategies more effectively.

The game for this study was developed from scratch using Unity 4.5.4 version and later upgraded to Unity 5.0.0 version. Unity was selected, because it has support for 2D graphics and it has built-in system for handling physics, collisions and joint hierarchies. In addition, Unity has a good support for various controller types and various platforms.

3.1.1 Graphics and character building blocks

The sprites and other graphics for the game were made in Photoshop Elements 10, using a Wacom Intuos5 tablet. For initial development, all the sprite art was drawn based on the original QWOP game to make sure that the original game mechanics can be replicated before mixing it up with dif-

Figure 3.1: Runner sprite sheet before and after the theme swap.

ferently designed character. Because original sprites were not available, the sprites were scaled and re-drawn based on the original graphics of the game. After theme swap in mid-game production, all the sprites were redrawn to match the new theme. A simple flat style was chosen for the sprites to enhance visual clarity, allowing the players to focus better on the actual play. The back and front body parts of the runner were made visually different, so that the player can easily recognize the pose of the character. References of actual Mars expedition equipment designs were used in the graphics development with some stylistics liberties taken here and there to suit the humorous aesthetics of the game.

Final versions of the runner sprite sheets can be seen in figure 3.1. The sprite sheets were uploaded into Unity and split into individual sprites inside the program. The pivot for each body part was set to the locations where the sprite needed to be rotated in relation to the parent body part.

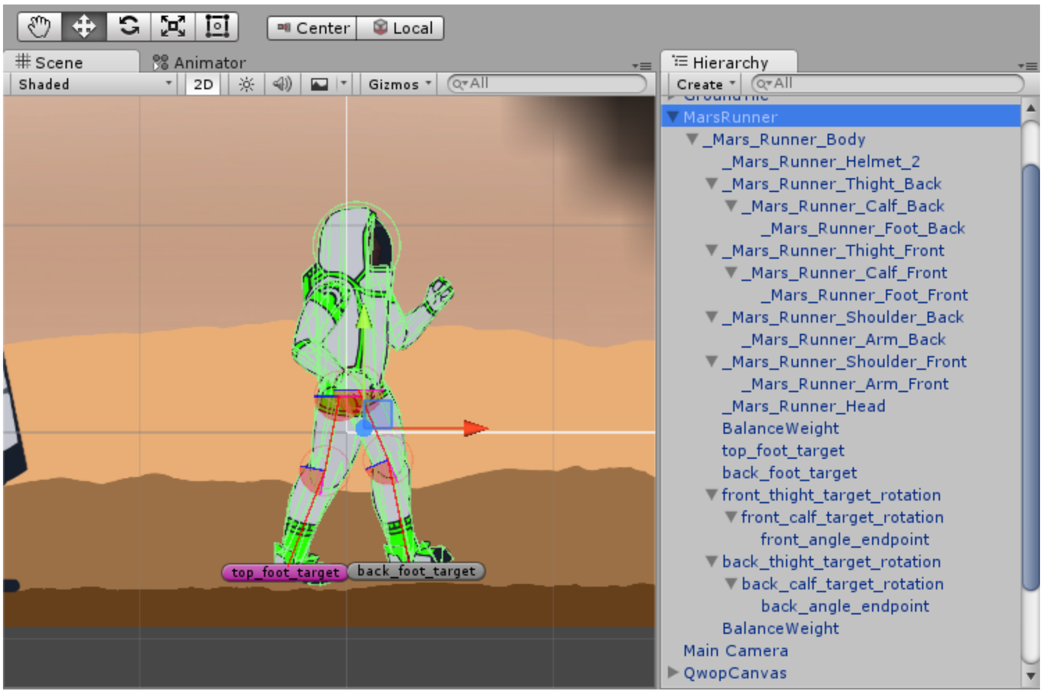


Figure 3.2: Implemented body hierarchy of the runner.

The body parts were arranged into hierarchical structure and each of the body parts were assigned a RigidBody2D and PolygonCollider2D handlers. HingeJoint2D components were used to define the connections between the body parts as well as define minimum and maximum angles for each joint. Each body part was given weight that approximately matched natural weight of each body part. Additional invisible weight was added below the runner to balance the otherwise very top-heavy mid-body sprite. Only joints under players control were the knee and hip joints (1 DOF per joint) controlling the rotations of the thighs and calves. Final Unity hierarchy along with colliders can be seen in figure 3.2.

3.1.2 Building control schemes

The test game was implemented with three selected controllers:

1. Keyboard
2. Gamepad (Xbox 360)

3. Motion and orientation detection game controller (Razer Hydra)

The keyboard represented the control interface with the original control scheme while the gamepad and motion control schemes were developed just for this test version of the game. These different controllers were chosen to represent different types of input that the user can use to control the game. The keyboard allows the user to use binary type of input that allows precise timing when an triggered action is turned on or off. The action triggered is always symbolic and the connection between input and the action on the screen always depends from the control mapping.

Gamepad represents analog control (the analog sticks of the gamepad controller). Analog input offers a sliding scale of input where the user has control of how much and how fast an action is triggered. Xbox 360 was chosen as gamepad controller because it can be plugged in to a computer, and it works with Unity out of the box.

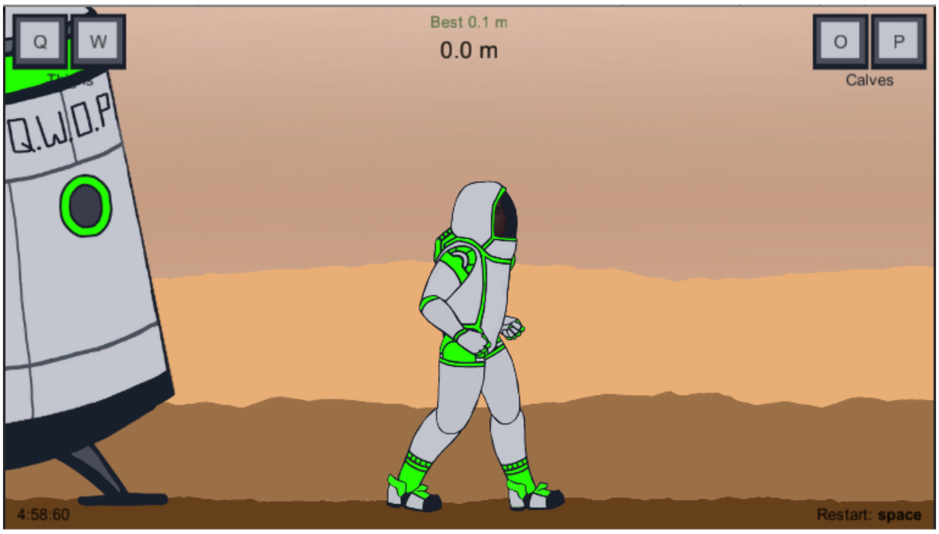
The motion control represents input by natural body movement, where the connection between the action and the motion triggered is more literal - to move the character the player must produce a similar motion with their own body. Razer Hydra was chosen as motion controller, because it's method of detecting absolute positions and orientations with weak magnetic field is very precise, allowing more accurate tracking of player's movements.

Each of the controller types had their own control scheme and some of the UI features were adjusted for each controller type. The inputs from each input devices were mapped to affect the hip and/or knee joint motor rotation speed either directly (keyboard) or through an IK system (gamepad, motion). Otherwise, all physical properties of the runner (e.g. body part weights, friction, joint limits and joint motor maximum torques and maximum rotation speeds) were kept the same for all different controller types. The final game interfaces for each controller type can be seen in figure 3.3. In addition to the game scene versions, several other scenes were developed for selecting the input device, for providing user basic play instructions, and for calibrating the motion controller 3.4.

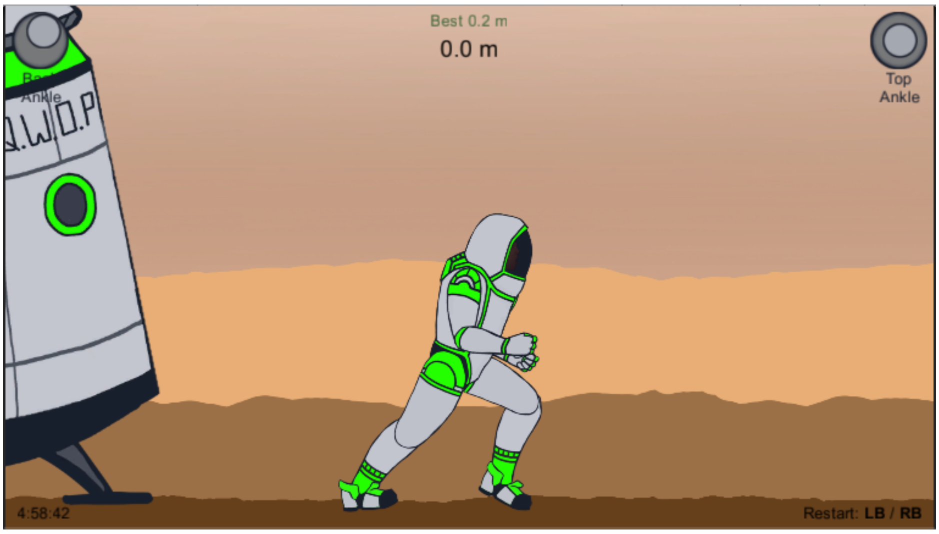
Keyboard controls

The keyboard controls were built to follow the original control scheme of the game, using the Q, W, O and P keys to directly control the joint motor rotation speed. The controls as well as the UI were built to resemble the original interface as much as possible.

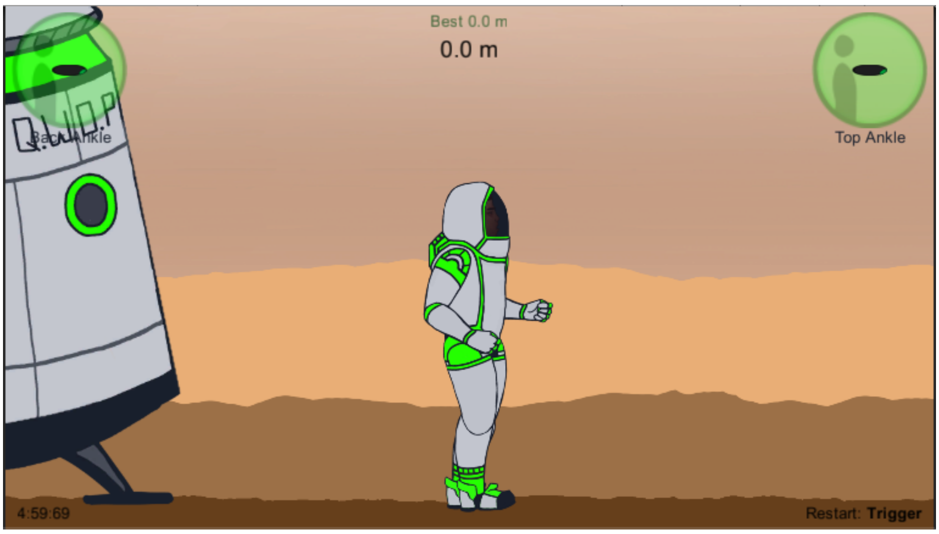
The QWOPs original control scheme uses less than intuitive mapping between the controls and the movements of the character's legs. Keys Q and



(a) Keyboard



(b) Gamepad



(c) Motion

Figure 3.3: Implemented game interfaces

(a) Input selection scene

(b) Instruction scene; Keyboard version

(c) Motion controller calibration scene

Figure 3.4: Additional game scenes

W are used to move the thighs in the opposite directions and keys O and P are used to move the calves respectively. For most of the users a single controller controlling a single part of the leg would be more intuitive [3]. On the other hand, the chosen control scheme simplifies number of variables that the user has to keep track of while controlling the character. The walking can be effectively done by just swapping between 2 input combinations (Q and P keys for the left stride and W and O keys for the right stride). The user must figure out this simplification on their own however, because the game doesn't instruct the players to use this strategy, and the strategy itself is hard to discover while playing the game.

Another benefit of using the keyboard controller with this control scheme is it's directness; the user can clearly see how each input affects the character's movements on the screen and user can time the actions better by choosing when to turn an action on or off.

IK-system

For the gamepad and motion controllers, we chose to use a different, and hopefully more intuitive, way to simplify the control of the joints of the runner. Inverse kinematics (IK) allows the user to set a desired target for a limb end point. The resulting angles for each joint are then calculated based on the IK target. Both gamepad and motion controller versions use the same IK system, but the mapping of inputs and the desired target are slightly different.

The IK system was built under the root of the runner as a separate system to allow calculating and keeping track of the target locations and the desired IK angles without having to worry about the physics. The distance between the target ankle and the hip root was used to calculate the rotation for the knee and after that the hip was rotated so that the distance between the actual IK-ankle position and target ankle position would be as small as possible. The IK system was visualised in the editor for debugging purposes, but on the actual game view the IK-system was invisible (see figure 3.5).

IK was mapped to joint motor speed using a proportional-derivate controller (PD-controller). The PD-controller is one of the simplest local feedback controllers used to compute joint torque that minimizes the difference between current state and the desired state for a single joint. It calculates the joint torque, τ_d , linearly proportional to the different between the current state, taking the difference between desired orientation θ_d and current orientation θ as well as desired angular velocity θ'_d and current angular velocity θ'. [18]

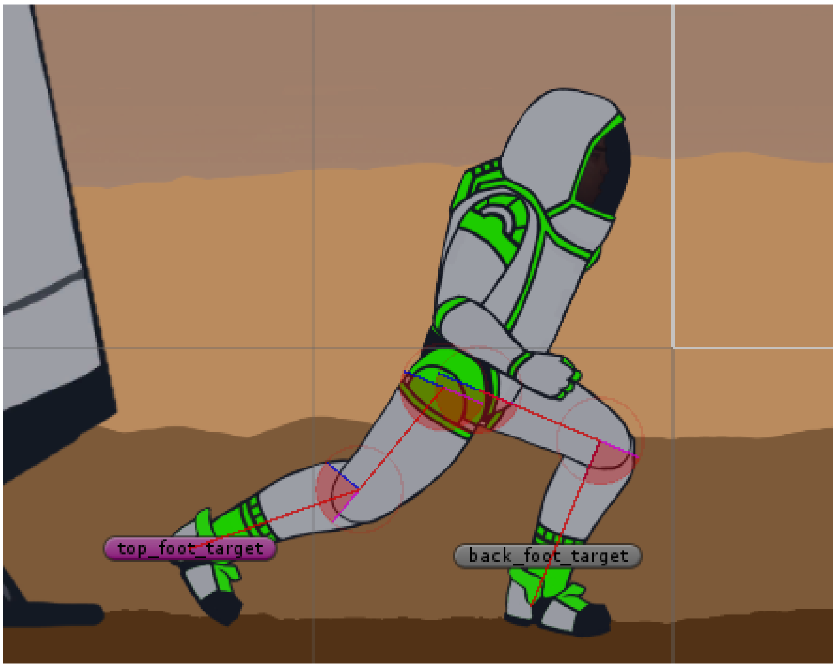


Figure 3.5: IK-system for the runner.

$$\tau_d = k_p(\theta_d - \theta) + k_v(\theta'_d - \theta') \tag{3.1}$$

The k_p (spring gain) and k_v (damping) are controller gains that regulate how responsive the controller is to the chances in orientation and angular velocity differences. Both of these gain variables have to be balanced manually. [18] For the test game, several parameters were tested during the development and for the final version, $k_p = 16.667$ and $k_v = 0.095$ seemed to be responsive enough to follow the IK without too much jittering. Joint motor speed to set ω_d was calculated by dividing target torque τ_d with maximum joint torque τ_m and multiplying it with maximum joint motor speed ω_m.

$$\omega_d = (\tau_d/\tau_m) * \omega_m \tag{3.2}$$

Inputs from both motion and gamepad controllers were mapped in local coordinate system relative to the hip root rotation so that same input would result always in similar motion for the character regardless of character orientation (e.g. input to bend the leg in front of character will always bend the leg in front of that character even if said character is upside down).

The inputs from both controllers were mapped so that the desired IK target would always be below the root hip level. The original QWOP character has some poses that have the ankle positioned above root hip level (e.g. leg bent backwards from both hip and knee joints), but these poses were not required for the walking, so they could be safely ignored. This limitation also helped to avoid a bug caused by the joint rotation limits. The IK system is not capable enough to rotate the leg below the character when the target ankle is above the hip. This causes a sudden jump from one extreme leg pose (hip and knee bent backwards) into the other (hip and knee bent forward) near the vertical mid-point of the character. When targets stay below the character, this doesn't happen and the IK system can calculate the mid-poses for the legs normally.

Gamepad controls

Gamepad controller was mapped so that each of the controller sticks would control one leg ankle target. Each extreme pose of the stick was set to refer to one extreme pose of the runner leg:

- Stick up: Leg bent in the middle
- Stick down: Leg straight in the middle
- Stick right: Leg in front of the character
- Stick left: Leg behind the character
- No-input (stick middle): Leg keeps the pose it had before releasing the stick.

All the other poses required for walking were derived from these extreme poses.

Because most of the users using a gamepad stick tend to use only the extremes positions to control a character, IK ankle target had max speed so that the dynamic leg would better follow the mid-poses between the desired extremes (e.g. keep leg knee bent when rotated along positive input y axis and leg straight when rotated along negative input y axis).

Motion controls

Motion control allows much more nuanced input compared to the analog control allowing mapping the controls to the IK system much more directly. For the motion controller, we decided to use crawling as motion analog for moving the legs (similar to "doggie paddle" motion has been used by users as locomotion metaphor [34]). The idea was that the player would move the controls in circular motion in front of the player and this rhythmic motion would be mapped to the positions of the character ankle IK targets.

From the control axes of the Razer Hydra input, positional z and y axes (depth and height movement) were chosen to be tracked for the IK. Plenty of other options could have been used for input mapping (Razer Hydra can accurately detect 6 degrees of freedom). This type of input was chosen for it's simplicity and because moving controllers in this way can be imagined as taking "steps" with the controller therefore increasing the chance that the controls would feel natural to the users.

The motion was mapped similar to the gamepad (up - leg bent, down - leg straight, forward - leg forward, backward - leg backwards). To measure these distances, the positions of both controllers were calibrated before the start of the game by holding both controller trigger buttons down for a few seconds and taking the average of both controller locations during the calibration (see figure 3.4(c)). The input mapping was programmed to favor big movements. This made it easier for the users to stay inside the mapped movement range around the calibrated mid-point as well. Another benefit for favoring big movements is that it lets the players to exert their bodies more, hopefully providing more chances for engagement.

3.1.3 Game testing and known issues

The physical properties of the runner, as well as the mapping parameters for each interface, were fine-tuned with trial and error to make sure that walking is possible with all versions of the interface (the author could walk consistently with every controller at least 6 m per game session). The game developed for this study was pilot-tested in several production stages to spot usability issues in the interface and to make sure that the control mappings remained somewhat playable. What made this testing difficult was that QWOP by its nature is very hard to play for even people who have practised the game a lot. It was difficult to determine if problems with the game were caused by the interface or by the difficulty of controlling a dynamic character itself.

More time for game-testing with end users and fine-tuning play parameters with the actual players would have been beneficial for the game, but in the given development time-frame this was not possible. Relying only on developer for gameplay parameters may set the game difficulty way too high, because developer has always had more experience with the interface compared to a normal player.

The remaining known issues related to the game controls and how they might affect the playability of the game are listed in table 3.1.

Input type	Description	Effect on playability
Keyboard	Holding WO keys down sometimes causes straight back leg to vibrate, causing enough movement for the character to slowly nudge forward.	Cheat strategy that allows player move safely long distances when discovered. May affect run results.
Gamepad & Motion	Leg friction with the ground may prevent the leg following the desired IK target position.	Obscures relationship between input and movements on screen, controller may seem unintuitive.
Gamepad	Player has to hold certain input positions with the analog sticks for the IK and the leg to reach the final target destination pose. Delay was originally meant to allow more stable walking using extreme stick positions.	Adds extra delay between user inputs and what's happening on the screen, controller may seem unintuitive.
Motion	The position of the IK targets for legs always depend of the positioning of the game controllers. Legs start in positions the player's hands were before restart or crash event.	No stable starting position. May cause excess crashes and resets just to get the starting position right.
Motion	The interface does not adapt to different ranges of movement.	The usability of the system depends on player movement style. Searching for optimal control range is required before the controller can be used effectively.
Motion	The "center" calibrated before starting the game with motion controller is easily lost, if the user switches their position.	User has to re-search the optimal input range every time the player's position change. Searching distracts player from the game.
Motion	The flat side-way view of the character as well as the way the controllers are visualized may encourage the user side-way motions when depth motions should be used instead.	Users may accidentally try to use un-mapped inputs while using the interface.

Table 3.1: Known issues

3.2 Measuring engagement and usability

The technical statistics were automatically collected during the gameplay. This is a good way to gather basic information of how the players play the game. To categorize players and to collect more data about more subjective parts of the playing experience we needed different data collection tools. We chose to use a questionnaire for this purpose. The questionnaire contained questions meant to gather data about basic background information about the players (e.g. age, gender, playtime average, gaming preferences, familiarity with the awkward game genre, QWOP proficiency, preferred interface versions) as well as standard measurement tools to gather data about the overall experience, engagement level, and the experienced usability of the used interfaces. The chosen standard questionnaires were:

- Self-Assessment Manikin (SAM)
- Game Engagement Questionnaire (GEQ)
- System usability scale

Each of the chosen standard questionnaires are introduced in more detail in the following sections.

The questionnaire was built with Google Forms. Some of the selected measurement tools, like the Self-Assessment Manikin could have benefited from a more versatile questionnaire tool (users were forced to pick the image from rating scale below the image instead of clicking the image directly). For the needs of this study the functions of the questionnaire tool were sufficient. The final version of the designed questionnaire can be found in appendix A.

3.2.1 The Self-Assessment Manikin (SAM)

Self-Assessment Manikin (SAM) is a quick non-verbal pictorial assessment technique for measuring subjective emotional reaction to an event or stimuli. It contains a series of images of a robot figurine designed to express emotional variation along three different dimensions - pleasure (pleasantness of the experience), arousal (intensity or level of alertness) and dominance (feeling of control and influence over the situation). In the assessment, the user is asked to select one image from each row representing these dimensions that corresponds to the emotion they are experiencing. [6]

To get the corresponding pleasure-arousal-dominance scores (PAD), the SAM result is transposed and scaled so that the final result scale is between [-1,1], where the positive axis represents positive and more intense emotions. [20] Interpretations for different PAD scores are listed in table 3.2.

PAD	Emotion	Interpretation
+P+A+D	Exuberant	Feelings of flow, optimal skill and challenge.
+P+A-D	Dependent	Task difficulty inspires determination and awe, low-skill and high-challenge.
+P-A+D	Relaxed	Easy relaxing task that allows mind to wander, high-skill and low-challenge.
+P-A-D	Docile	Intrinsic motivation keeps experience positive despite of boring start, low-skill or low-challenge.
-P-A-D	Bored	Task is easy and repetitive, low-skill and low-challenge.
-P-A+D	Disdain	Task way too easy and annoying, high-skill and low-challenge.
-P+A-D	Anxiety	Daunting task that inspires fear, low-skill and high-challenge.
-P+A+D	Hostile	Task inspires anger despite of optimal challenge, high-skill and high-challenge.

Table 3.2: Pleasure, arousal and dominance (PAD) score interpretations [20]

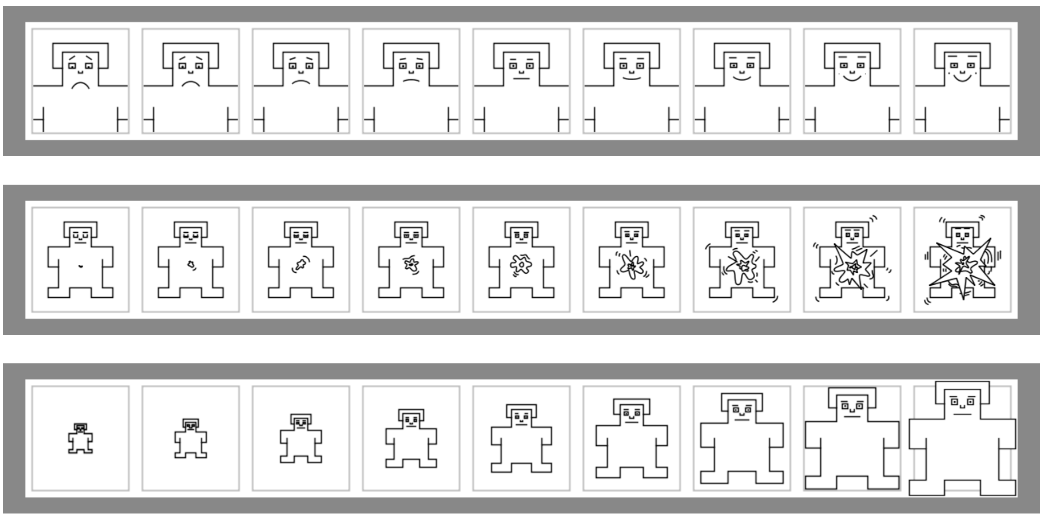


Figure 3.6: SAM pleasure, arousal and dominance measurement scales [22].

SAM has been used effectively to measure emotional response in various situations and it's results have been widely validated and standardized. Without verbal or cultural barriers it works well even in multilingual environments and can be completed with minimal effort, causing less respondent wear out than many other assessment tools. [6] Newer measurement tools have been created and evaluated [11], but we use SAM here for it's wide usage and simplicity.

In this exam, the 9-scale version of SAM was used (see figure 3.6). In the pilot version, the users had trouble understanding the words arousal and dominance, so these terms were switched to "control" and "intensity" in the questionnaire.

3.2.2 Game Engagement Questionnaire (GEQ)

Game Engagement Questionnaire (GEQ) is a standard questionnaire developed to evaluate engagement level the users have when interacting with a game. It consists of 19 questions rated on a 1-5 point scale, measuring different aspects of engagement like immersion, presence, flow and absorption in a continuum. Individual questions are rated with Rasch model so that questions corresponding to lower levels of engagement (immersion) are easier to agree with than questions responding to high levels of engagement (absorption). Individual scores are averaged to form the final overall engagement score. [7] The original GEQ questionnaire questions can be seen in table 3.3.

There are alternative standard questionnaires that are also developed to measure experience while playing the game, such as Game Experience Questionnaire [21] and Gaming Engagement Questionnaire [12]. This questionnaire was chosen because it's relatively short, the validly of the questionnaire has been empirically tested, its widely used and it simplifies the aspects of engagement into a single comparable score.

While the GEQ is widely used, it might not be the best method for evaluating this type of game. The GEQ was originally designed to measure the violent game's potential impact on player based on the engagement level of the game, thus leaning towards assessment of individual child's tendency to become involved in violent game rather than assessing the game itself. It contains some questions not related to gaming itself (e.g. I feel scared). [33] GEQ is also aimed at highly-violent and highly-immersive games and may not work as well for non-violent and less-immersive games. [16]

The questionnaire was pilot-tested, and some testers at the pilot test had trouble understanding some sentences in the questionnaire partly because English was their secondary language. The problematic sentences "I get wound up" and "I feel spaced out" were replaced with "I get wound up,

Index	Question
1	I lose track of time
2	Things seem to happen automatically
3	I feel different
4	I feel scared
5	The game feels real
6	If someone talks to me, I don't hear them
7	I get wound up
8	Time seems to kind of stand still or stop
9	I feel spaced out
10	I don't answer when someone talks to me
11	I can't tell that I'm getting tired
12	Playing seems automatic
13	My thoughts go fast
14	I lose track of where I am
15	I play without thinking about how to play
16	Playing makes me feel calm
17	I play longer than I meant to
18	I really get into the game
19	I feel like I just can't stop playing

Table 3.3: Game Engagement Questionnaire (GEQ) items [7]

tense or wired" and "I feel spaced out, disoriented or lost in thought" to increase the participants chance of understanding the sentences correctly.

The original question list also contained some questions had poor fit to the examination method used. "I play longer than I meant to" and "I feel like I just can't stop playing" were most problematic, because for our game each game session was timed to be 5 minutes and the player was not allowed to stop examination mid-game, causing arbitrary answers depending how the user interpreted what the question could mean in the current game context. This problem was not noticed in the questionnaire pilot-testing and thus remained even in the final version of the questionnaire.

3.2.3 System usability scale (SUS)

To collect data about usability of the game and the game interface, a system usability scale (SUS) was used as a standard questionnaire test. SUS is a robust and standardised questionnaire for evaluating usability of a system, product or interface. It consists of 10 statements that the user is asked to rate on 1-5 scale. The answers are combined to form a SUS-score from 0-100 with the average score for the test being around 68. [8] SUS questionnaire questions can be seen in table 3.4. There are rating scales developed for SUS that allow the well the product or interface was scored compared to other products graded with the same tool. An example of such grading scale can be seen in figure 3.7.

In this experiment, a positive statement version of SUS was used. Inclusion of negative statements as well as positive ones didn't offer any extra advantages and tends to increase the chance of users to accidentally agree with negative statements. The researcher could also easily forget to invert the rating scale for these sentences, causing miscalculated results. [41] Some wordings of the questionnaire were adjusted (e.g. replacing "system" with "interface" and "cumbersome" with "awkward") to make the system fit the exam better and to help non-native English speakers to understand questions easier. Minor adjustments should not affect the results of the questionnaire. [41]

In the questionnaire used in this test (see A), the instruction of "Answer the following questions based on your experience with the game controller", may have been a bit misleading since some of the test participants asked if they were meant to answer based on their experience with the controller or the overall game interface. "Game interface" might have been a better wording for the questionnaire. This problem didn't come up in the pilot test, but it might have affected the test results.

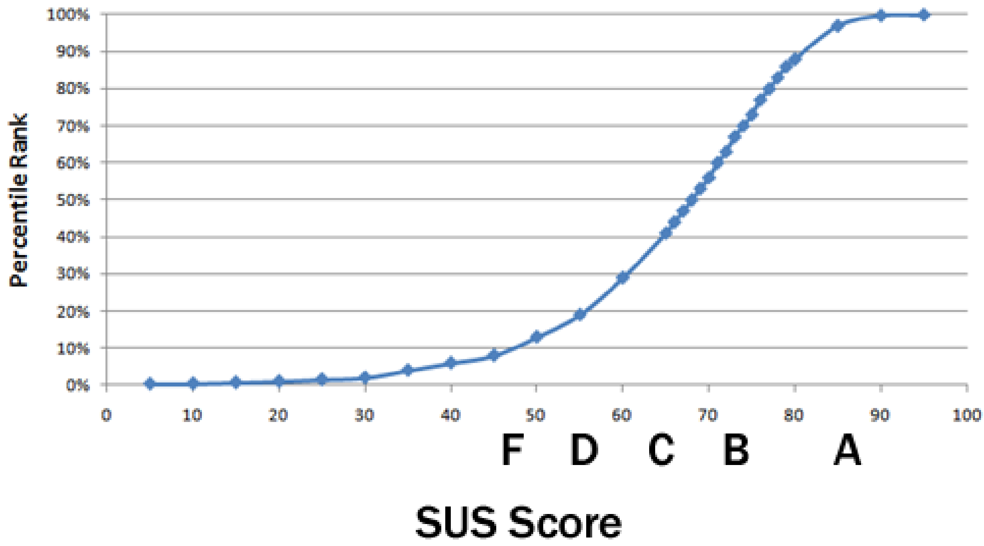


Figure 3.7: SUS grading scale [40]

Index	Question
1	I think that I would like to use the interface frequently.
2	I found the interface to be simple.
3	I thought that the interface was easy to use.
4	I think that I could use the interface without the support of a technical person.
5	I found that various functions in the interface were well integrated.
6	I thought there was a lot of consistency in the interface.
7	I would imagine that most people would learn how to use the interface very quickly.
8	I found the interface very intuitive.
9	I felt confident using the interface.
10	I could use the interface without having to learn anything new.

Table 3.4: System Usability Scale (SUS) items [7]

Chapter 4

Results

The data was mostly collected in the Aalto University campus area and most of the participants were university students. The test sessions were done on several different days during a two week period. Each test session consisted of 5 minutes of playing with each input device with short questionnaire before, after and between the play-sessions. The order of the different input devices across the exam sessions was counterbalanced and 18 players were tested in total. A basic laptop was used to run the test game and to collect the data from the questionnaires. Each participant received a movie-ticket as a reward after the test.

Before each input device, the players were instructed briefly which part of the input device they should use to control the game. Users were not instructed on how the controllers affect the character in the game, because figuring out how to use the controllers is one of the major factors in QWOP difficulty. Allowing the users to figure out the control on their own should reveal which of the control schemes felt intuitive to the users and which didn't.

Each play session was observed and the players were asked to think out loud while playing. Any notable comments, reactions or play-strategies were written down on a notepad. The players were allowed to ask definitions of any unclear questions in the questionnaire and were allowed to answer to open ended questions either in English or in Finnish.

All data gathered from the play-tests and from the questionnaires was saved and imported to Excel spreadsheets. In addition to Excel, Minitab and SPSS were used to help in analyzing and visualizing the results.

4.1 Basic statistics and awkward game genre familiarity

The average age of participants was 25 (M=24.61, SD=3.71). The players estimated their average gaming time per week to be around 9h per week (M=9.04, SD=8,59) with females playing considerably less time per week compared to male gamers (female M=4.86, SD=5.13, Male M=13.22, SD=9.54). Most of the test participants reported playing games often or very often (N=10) while only two reported playing games rarely or had never played games.

Most of the players (N=11) had played some of the example games belonging to the awkward game genre. Games used as example games were QWOP, Octodad, I am Bread, Surgeon Simulator, Real Summer Sports Simulator, Toribash and Trials (see figure 4.1). Most well known of the example games was QWOP (N=9) with Trials (N=8) as close second. Some of the players (N=7) had never played any of the example games listed.

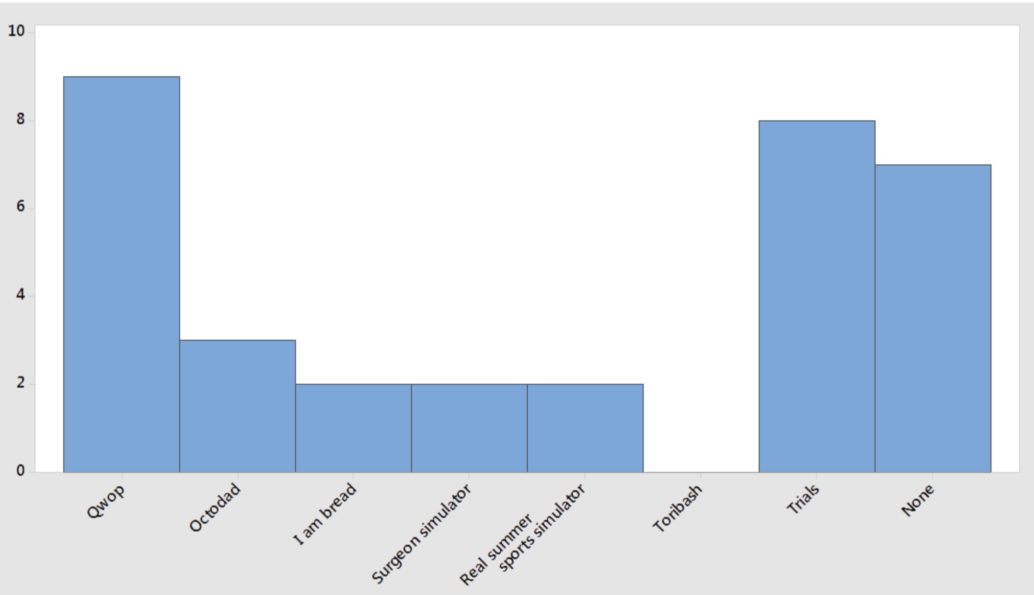


Figure 4.1: Awkward games tried by the tested players.

Half of the players had not played QWOP before (N=9). Most of the players who had played the game reported that even if they had played the game before, they had never made much progress in it (N=8). Only one of the players reported that they could walk or run the required 100 m to beat

QWOP. While answering, the player told that they had used a crawl tactic to safely pass the game and had not actually managed to walk or run through the whole game.

4.2 Game data

The following data was gathered from each play-session of the game:

- Player id and input type to recognize and categorize the play session.
- Overall record run distance.
- Each crash (helmet hits ground forcing player to restart level), restart (player chooses to restart the level) and time-out (play time over) events. Information collected of each event were the time of their occurrence compared to the total game session length, time since the last restart event had happened and the current distance run when the event occurred.

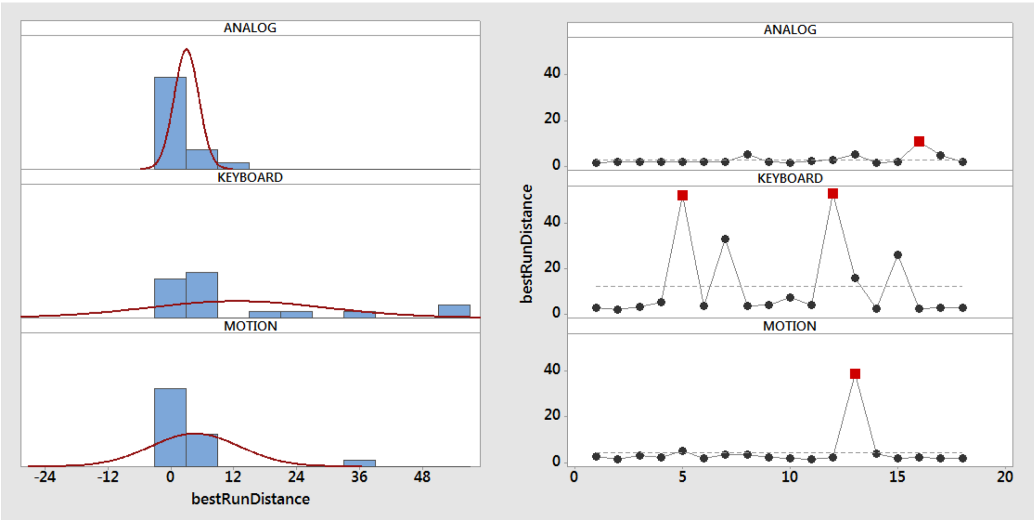
It would have been beneficial to also record the position of the player at regular intervals to map out how the runs proceed in the game. Unfortunately this was realized when all the data had already been recorded.

The differences between record distances, run distances and the reset rates for each input type are analysed in the following sections.

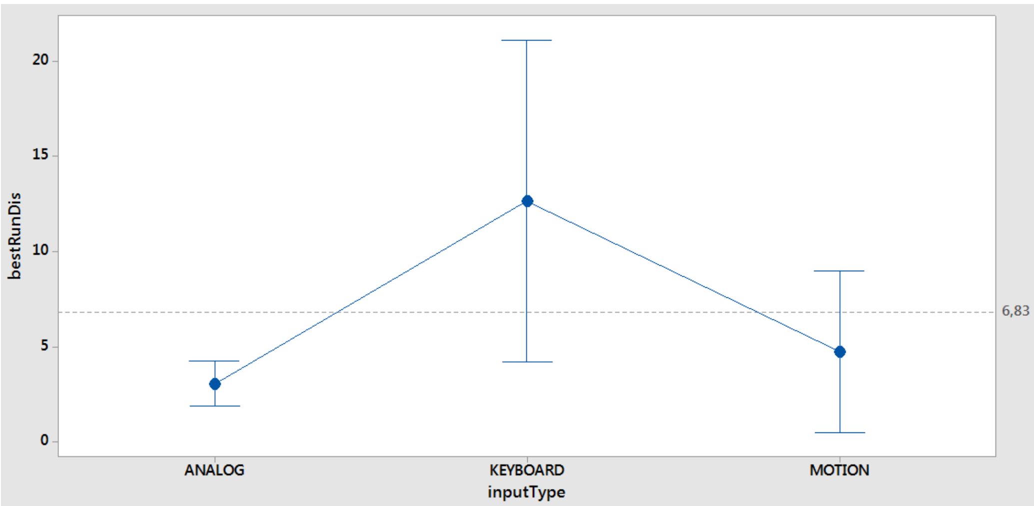
4.2.1 Record run distances

For each session, the run that produced the longest distance was chosen as the final result of the game. While playing the game, the users clearly strived to beat their own record and expressed joy every time they managed to get a little bit futher into the game. Long runs were rewarded with extra content (10 m=image of a mars rover and a 20 m=cute alien creature). The users were not informed of this extra content before playing the game.

Because of QWOPs steep learning curve and difficulty, distribution of even the best runs tended to be steep and centered around 0 m. For all the controller types, the average record run was around 6 m (M=6.83, SD=11.67). Majority of the record runs were centered pretty close to each others, aside from spike records for users who figured out a safe tactic to move forward in the game.



(a) Histogram of record run distances by input type.



(b) Main effects of record run distances by input type.

Figure 4.2: Histogram and main effects diagrams of record run distances by input type.

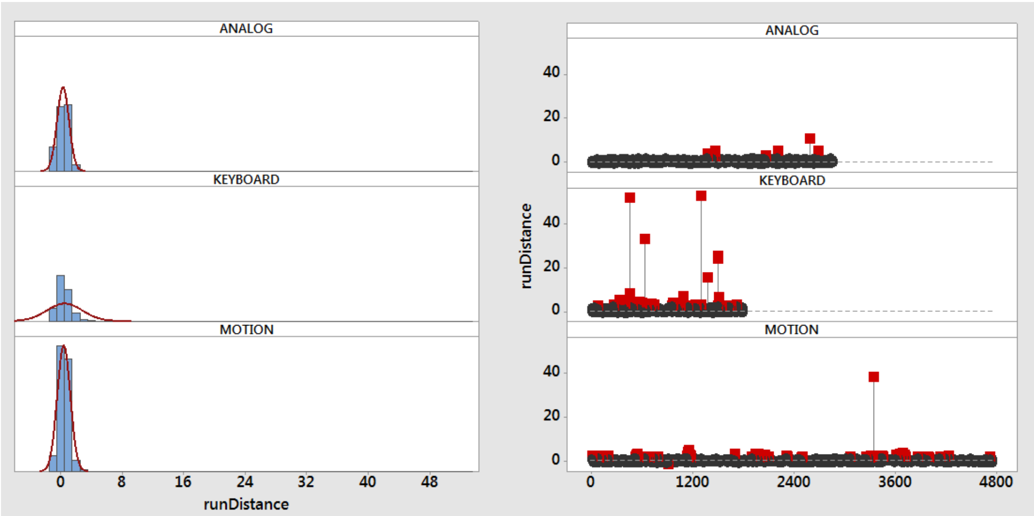
When categorized by input type, the means and distributions are slightly different (see figure 4.2). The runs with the analog device are the shortest (M=3.08, SD=2.36), while the users were slightly more likely get better records with the motion (M=4.74, SD=8.56) and keyboard (M=12.67, SD=17.04) input types. When looking at individual records, we can see that the users had slightly greater chance to get a really good run with the keyboard input type compared to the other input types suggesting that the users were more likely to find good run strategies using this input type. On the other hand, the results varied quite a lot with motion and especially keyboard input type, suggesting that there were differences with how well each of the players were able to use each of the interfaces.

To find out if the choice of input type had significant effects on the run records, a one-way within subjects ANOVA was conducted. No significant effects were found (Wilks'Lambda=0.75, F(2,16)=2.66, p=0.100). This result suggests that the input type didn't have any notable effects on the overall run records. All though, the one-way ANOVA result is close to being significant so it could be possible that more prominent effects would have been found if more test subjects had been studied.

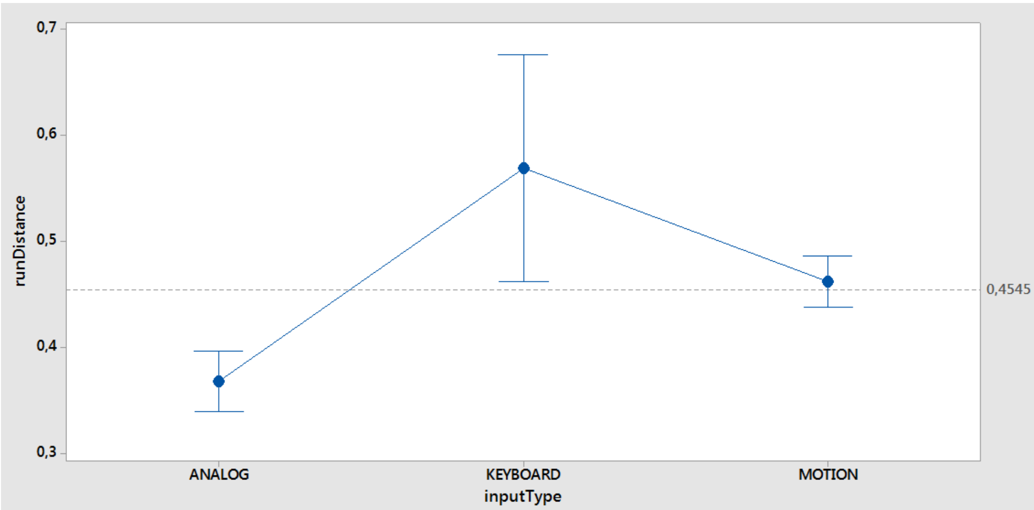
4.2.2 Run distances

In addition to run records, it is also interesting to compare how well the players did with a typical run in the game. Total of 9442 run events were recorded with considerably more runs (and there for more restarts and or crashes) were made with motion controller (N=4763) compared to keyboard (N=1807) and gamepad (N=2872) controllers. With this many data points the differences between the different input types were much more distinguishable(see figure 4.3). The histograms of both gamepad (M=0.37, SD=0.78) and motion (M=0.46, SD=0.85) controllers are much more steeper compared to the keyboard (M=0.57, SD=2.32) which is more widely spread.

To compare if the input type had effects on the average run distances, we calculated average run distance for each player for each input type and conducted a one-way within subjects ANOVA to see if the input type had any significant effects on them. A significant effect was detected (Wilks'Lambda=0.68, F(2,16)=3.70, p=0.048). Three paired samples t-tests were performed as post hoc comparison of the conditions (level of significance adjusted by number of tests to 0.017). However, in the t-test there were no significant differences in run distance averages between analog (M=0.34, SD=0.21), keyboard (M=0.81, SD=0.84) or motion (M=0.48,SD=0.20) input types (analog-keyboard: (t(17)=-2.33, p=0.032); keyboard-motion: (t(17)=1.68, p=0.111); motion-analog: (t(17)=2.11, p=0.050)).



(a) Histogram of run distances by input type.



(b) Main effects of run distances by input type.

Figure 4.3: Histogram and main effects diagrams of run distances by input type.

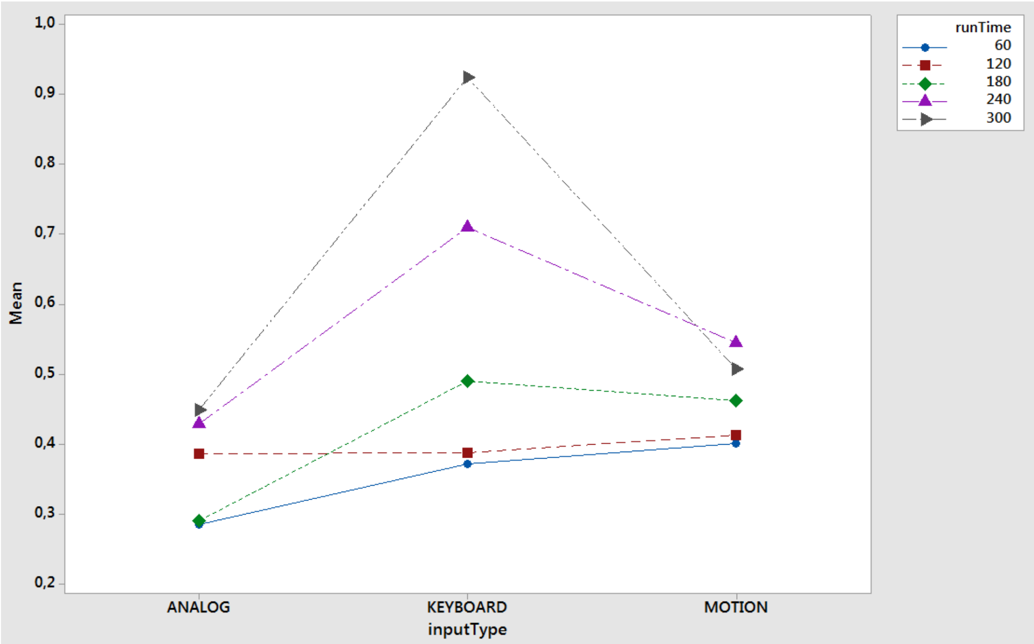


Figure 4.4: Interaction plot of run distances grouped by their occurrence during the play session.

There was some learning present with all of the controllers (see figure 4.4). With every controller type, the result means improved over time, with lower results near the start of the game and slightly improving towards the end of the game. The effect is not very strong, since 1 m equals the distance the character can move just by falling forward. Even slight difference in the run means however, could imply that the players were confidently able to move and stay upright at least a little bit longer.

Gamepad controller benefited from the learning effect the least - the improvement was slow both at the start and at the end of the game, and the total distances run were short in general. With motion controller overall learning was not that much better except that the improvements kept happening at constant rate even near the end of the game, indicating that more improvement with the results could have happened if more playtime was given to the players. The keyboard input type seemed to benefit from learning the most, with users getting significantly better results near the end of the game.

4.2.3 Restart frequencies

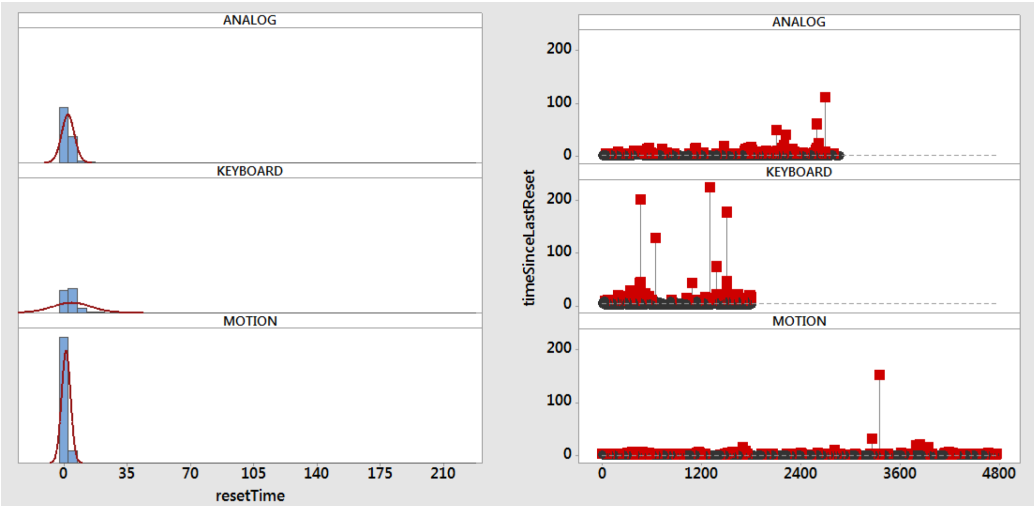
In addition to the run distance, it is also useful to see how often the character fell in the game with each controller type and if the falling rate improved during the course of the game. For all the controller types, the reset rates were steep, with motion controller having clearly the fastest reset rate (M=1.57, SD=2.48) compared to the gamepad (M=2.63, SD=3.52) and keyboard (M=4.72, SD=10.67) controllers (see figure 4.5). Across all the controller types, the restart events were far more common compared to crash events, indicating that the players often restarted the level when they saw that their character was about to fall or when the game didn't proceed as they wanted.

To compare if the input type had effects on the average reset times, we calculated the average reset time for each player for each input type (analog: M=2.93, SD=1.09; keyboard: M=6.58, SD=5.94; motion: M=1.67, SD=0.47) and conducted a one-way within subjects ANOVA to see if the input type had any significant effects on them. A significant effect was detected (Wilks'Lambda=0.26, $F(2,16)=23.08$, $p<0.001$). Three paired samples t-tests were performed as post hoc comparison of the conditions (level of significance adjusted by number of tests to 0.017). There were significant differences between reset time average scores for keyboard and motion ($t(17)=3.56$, $p=0.002$) and also with motion and analog ($t(17)=-5.14$, $p<0.001$) input types. The differences between analog and keyboard input types were not significant ($t(17)=-2.51$, $p=0.022$). These results suggest that the input type had an effect on the reset time averages. The users were significantly more likely fall with the character when they played the game with a motion controller compared to the other controllers.

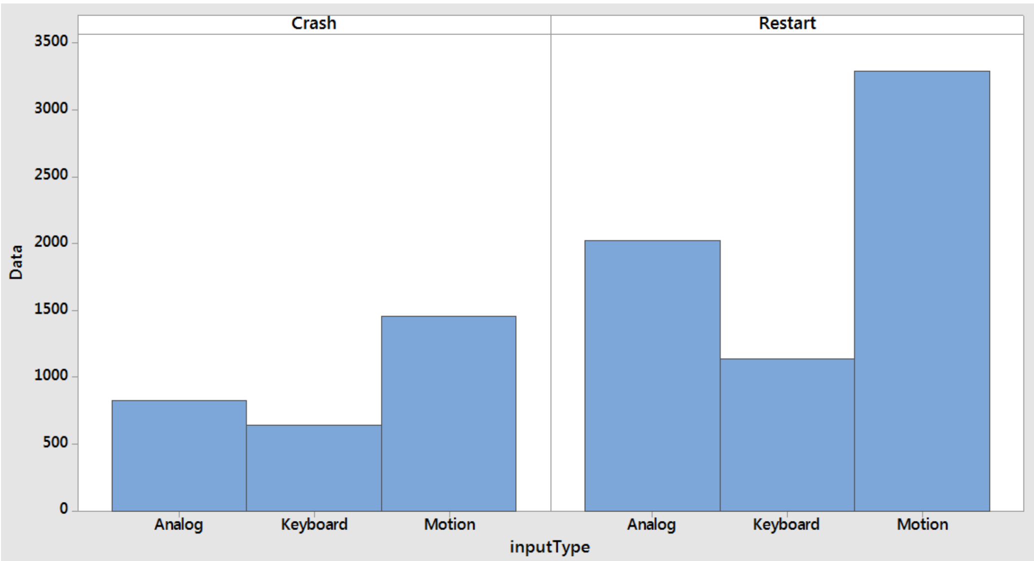
The differences in the reset rate are even more prominent when grouped by the time they occurred in the run (see figure 4.6). The motion controller seemed to have far shorter reset rate for the whole duration of session with no significant improvements. With the analog controller, the results didn't improve much either, but the users were more likely to stay upright at least a little while longer. The best reset rate was with the keyboard controller. The users managed to stay upright with this input type quite well and the reset rate got better near the end of the play session.

4.3 Usability and engagement

The results from each questionnaire were imported to Excel. The data from general background questions and engagement answers were gathered to sep-



(a) Histogram of time before run restart by input type.



(b) Bar chart of all crash and restart events by input type.

Figure 4.5: Histogram and main effects diagrams of run restarts by input type.

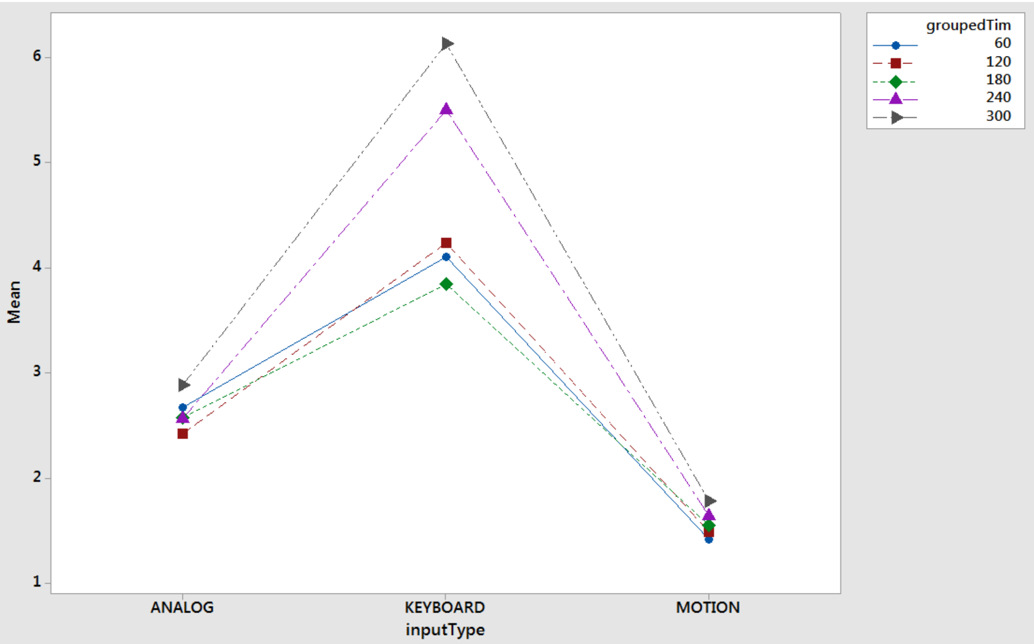


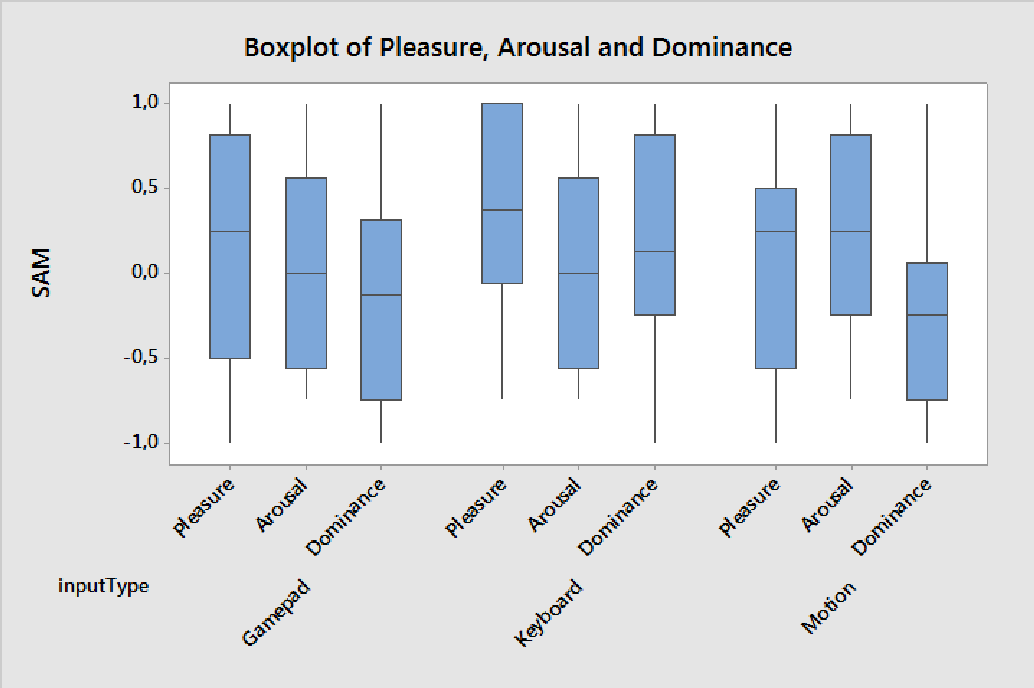
Figure 4.6: Interaction plot of run restarts grouped by their occurrence during the play session.

arate tables so that their results could be analyzed more effectively. Some of the text replies were converted to numbers to help out calculations when needed. SAM, GEQ and SUS scores were calculated from the cleaned data in Excel and transported to Minitab and SPSS for more detailed analysis.

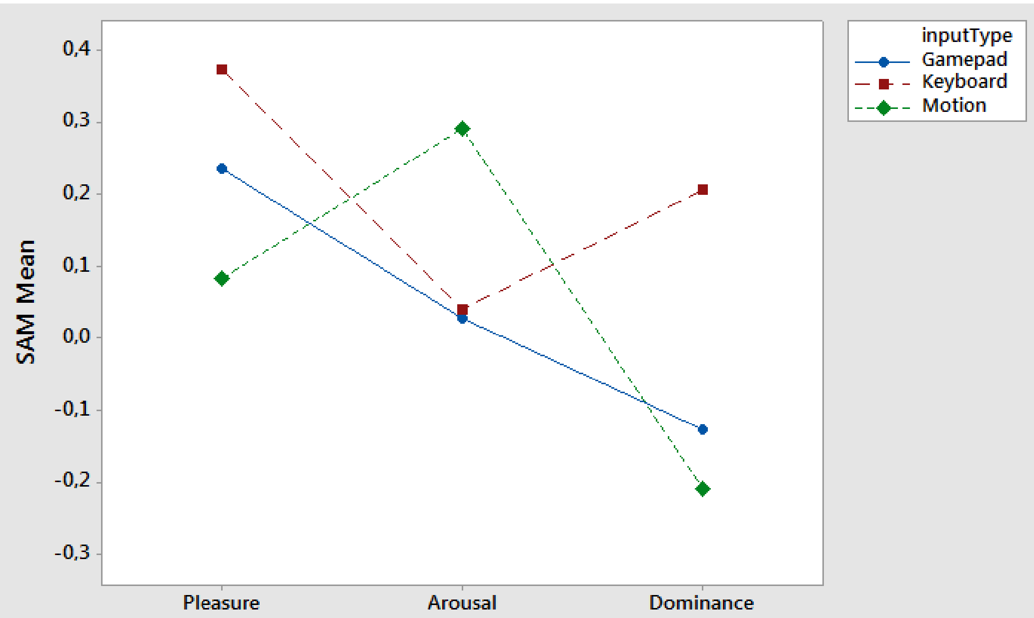
4.3.1 SAM

The PAD dimensions were calculated for each input type based on the SAM reposes of the tested users. The PAD evaluations varied greatly between the players, indicating that the players could have very different play experiences even with the same input device(see figure 4.7 and table 4.1). The overall pleasure dimension was mostly positive for all input devices, with motion controller scoring slightly more arousal compared to the other input devices. The largest difference between the PAD dimensions between the controller types was with dominance, with the keyboard controller scoring a positive dominance score while the motion and gamepad got negative ones, which indicates that the users did not feel like they were in control of the situation when using these controller types.

A within-subjects one-way MANOVA was conducted to compare effect



(a) Boxplot of PAD scores by input type.



(b) Interaction plot of PAD dimension means by input type.

Figure 4.7: Boxplot and PAD dimensions by input type.

PAD dimension	Input type	Mean	SD
Pleasure	Gamepad	0.24	0.68
	Keyboard	0.38	0.56
	Motion	0.08	0.65
Arousal	Gamepad	0.03	0.61
	Keyboard	0.04	0.63
	Motion	0.29	0.57
Dominance	Gamepad	-0.13	0.64
	Keyboard	0.21	0.67
	Motion	-0.21	0.63

Table 4.1: Pleasure, arousal and dominance (PAD) means and standard deviations

of input type on the PAD dimensions. We did not find any significant multivariate effects across PAD scores between the users (Wilks'Lambda=0.52, F(6,12)=1.88, p=0.165). A larger sample size could have helped with detecting the differences more accurately.

To see what types of emotions each input type caused, the PAD dimension scores were simplified to positive and negative values and a count of each PAD dimension combination for each input type was performed (see figure 4.8). The most common emotion for all the input types was the the PAD combination that corresponds to the feelings of joy and flow (P+A+D+) with the exception of motion controller where the feeling of determination and awe when faced by a difficult task (+P+A-D) was more common. The emotion of awe (+P+A-D) was also prominent with the gamepad controller but not that much with the keyboard controller. Along all the input types the next common emotion was boredom or apathy (-P-A-D) common to low-skill low-challenge situations. This indicates that these users might have given up even trying to proceed in the game at some point and just waited for the play session timer to run out so that they could get their reward. Positive experiences (positive pleasure) were in overall more common than negative experiences (pleasure negative).

4.3.2 GEQ

The final GEQ scores for different interfaces were quite similar (see figure 4.9). The only notable difference between the GEQ scores was that the motion controller had a slightly wider distribution of GEQ score (M=2.36, SD=0.79), but otherwise the GEQ scores did not differ that much (Gamepad: M=2.32, SD=0.60; Keyboard: M=2.45, SD=0.53). All of the score means

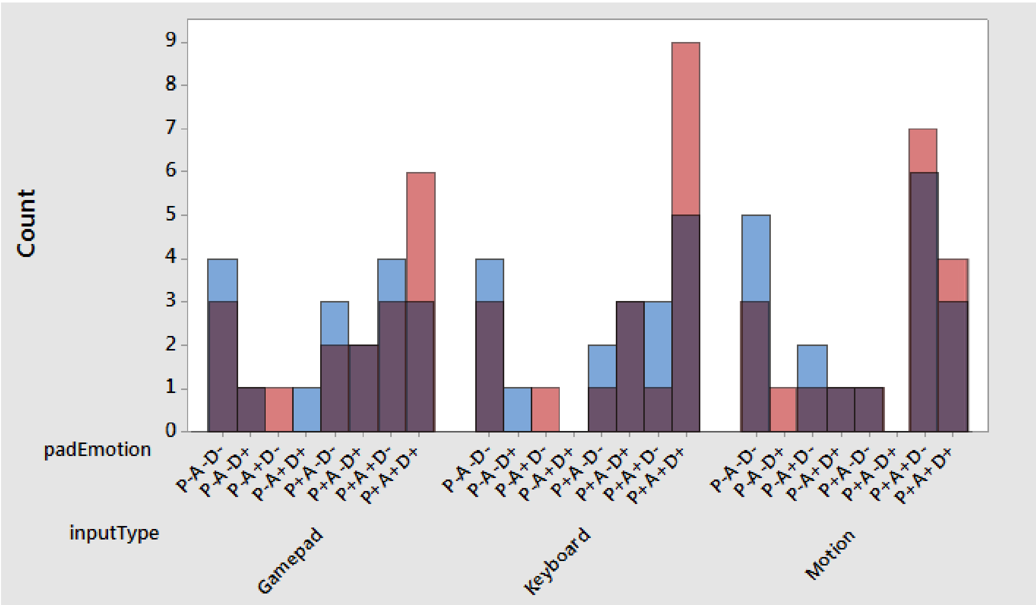
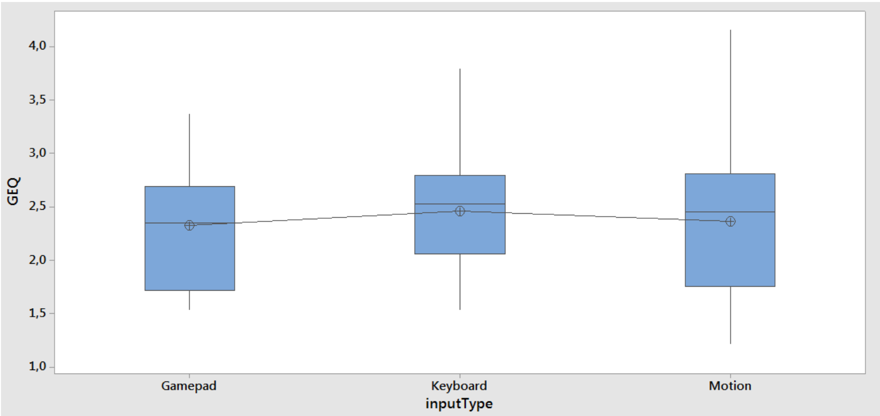


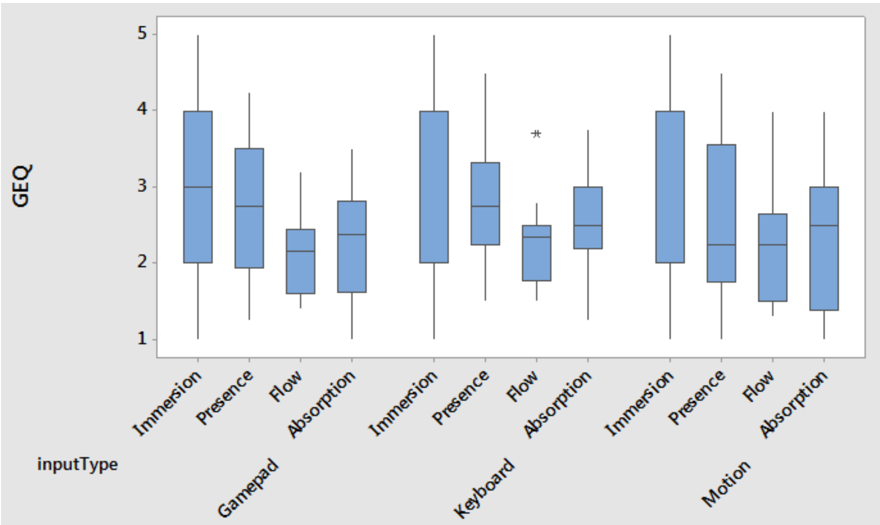
Figure 4.8: PAD dimension counts by input type (unsure cases positive interpretation is pink and negative interpretation is blue).

were below 3, meaning that the players agreed with less than half of the questions in the questionnaire, indicating relatively low level of engagement. A within-subjects one-way MANOVA was conducted to compare effect of input type on the GEQ results, using immersion, flow, presence and absorption score averages as the dependent variables. We didn't find any significant multivariate effects on the GEQ results based on the input type used (Wilks'Lambda=0.41, F(8,10)=1.79, p=0.191).

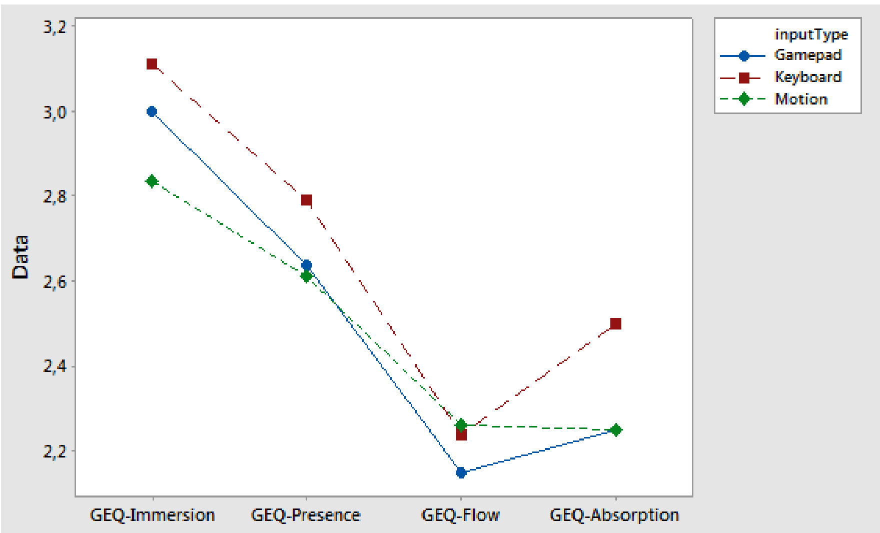
If we look individual answers per input type (see figure 4.10(a)), we can notice that the answers to each question did not differ that much between the input types. We can also notice that questions measuring flow scored lower questions that were supposed to measure absorption, which does not fit the GEQ presumption that the questions measuring absorption should be the hardest to agree on [7]. The measurements of the GEQ may not be accurate, since many of the players seemed to have difficulties answering the questions of the questionnaire even with the modified version of the questions. Quite many of the questions did not fit that well to the timed uninterrupted examination setting (e.g. "I lose track of time", "I play longer than I meant to","I feel like I just can't stop playing", "I don't answer when someone talks to me", "If someone talks to me, I don't hear them") or were geared towards high-immersion and high-engagement type of games that were a poor fit for



(a) Boxplot of GEQ scores by input type.



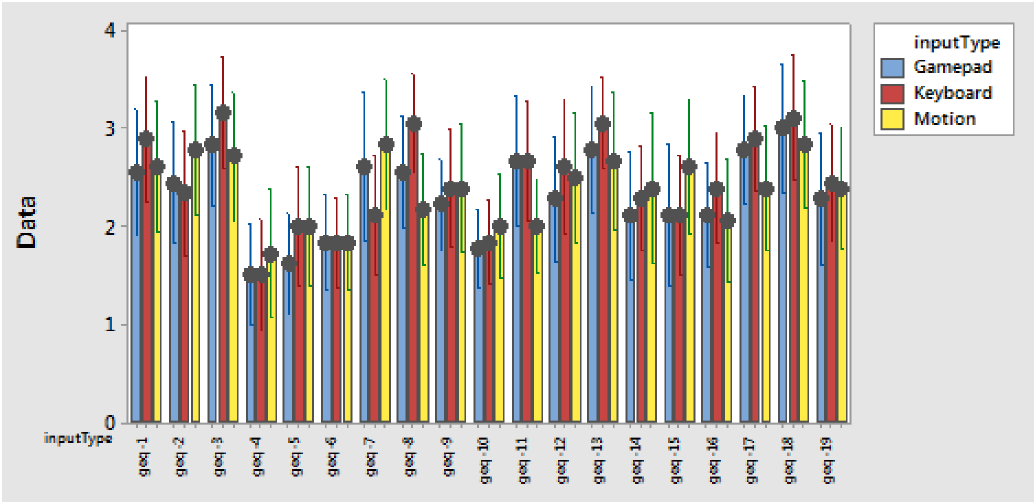
(b) Boxplot of GEQ scores per engagement level



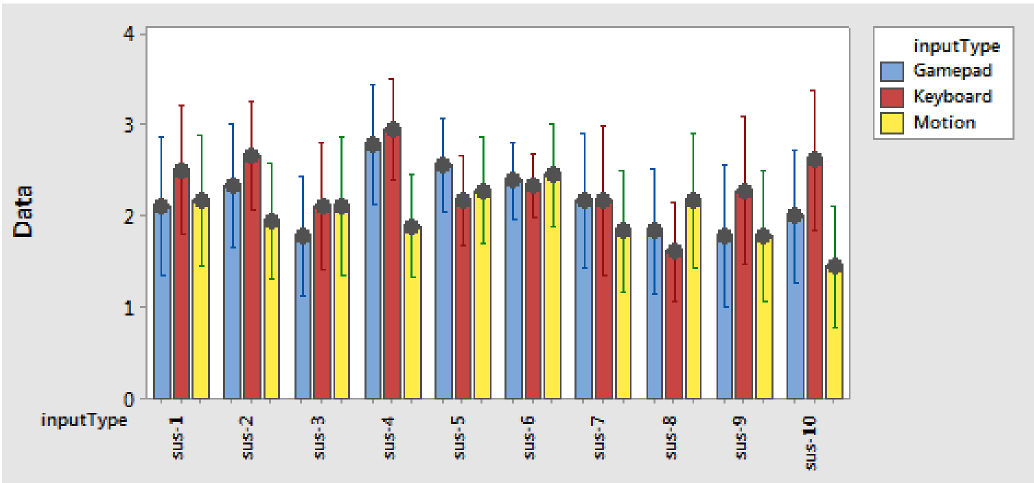
(c) Interaction Plot of GEQ scores per engagement level

Figure 4.9: GEQ total and dimension scores by input type.

measuring a 2D awkward game where the immersion with the game world and the character isn't as strong (e.g. "The game feels real", "I feel scared"). This may have affected the reliability of the results.



(a) GEQ answers



(b) SUS answers

Figure 4.10: Individual GEQ and SUS questionnaire answers by input type.

4.3.3 SUS

The SUS score was very low for all the different input interfaces used in the study (see figure 4.11). The average average score across every input type

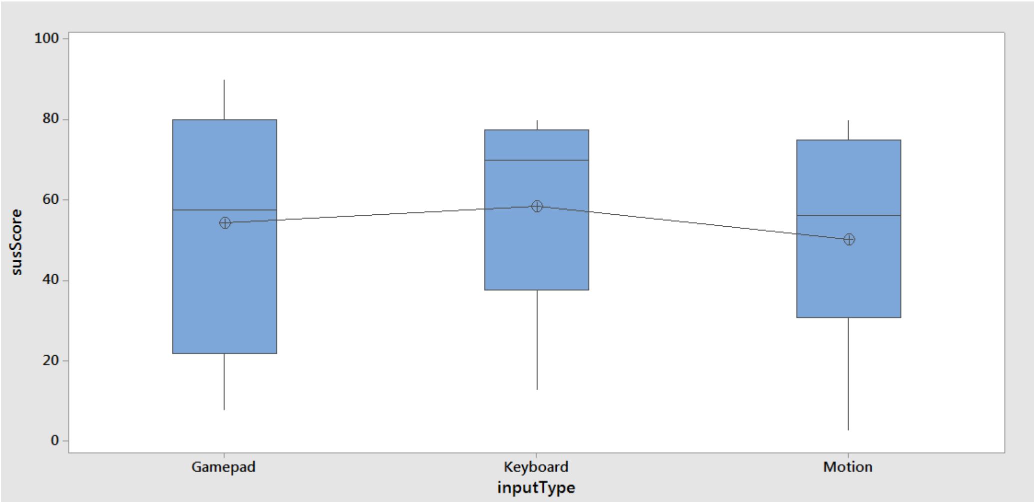


Figure 4.11: Boxplot of SUS scores by input type.

was 54, with keyboard having the highest score (M=58.47, SD=23.53) and gamepad (M=54.31, SD=26.79) and motion (M=50.14, SD=26.73) having lower scores. Based on the SUS grading scale (see figure 3.7) the scores mean that the interfaces were evaluated to have usability of worse than 34% of the products evaluated with the test. We conducted one-way within subjects ANOVA to find out if the input type had any significant effects on the SUS total scores. No significant effects were found (Wilks'Lambda=0.83, F(2,16)=1.61, p=0.230).

Looking at the individual question answers (see figure 4.10(b)), we can notice that all the question scored quite poorly and that the answers between different input devices were quite similar. The biggest differences between answers were to questions "I think that I could use the interface without the support of a technical person" and "I could use the interface without having to learn anything new" with both of these questions gamepad and keyboard interfaces getting slightly better score than the motion controller, suggesting that the motion controller may have had more usability problems compared to the other interfaces as well. The low overall SUS score can be partly explained with the difficulty of the game. On the other hand, some of the controller types including the original interface may have had some clear usability issues that may have also contributed to the low SUS score.

4.4 Interface preference

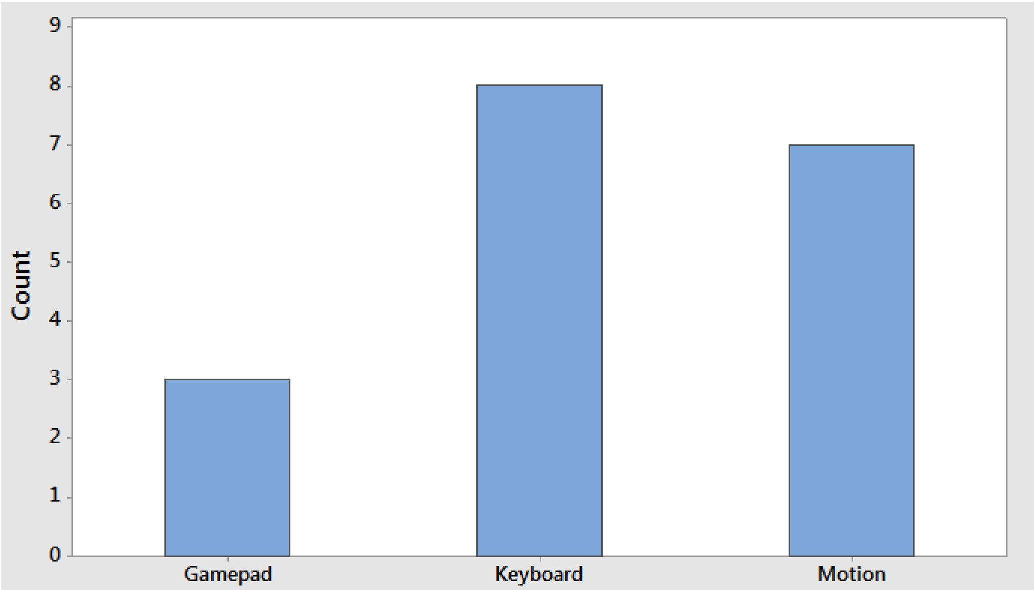
After playing the game with all the different input types, the players were asked to choose their most and least preferred input type as well as to explain why they liked or disliked them. All of the input types were chosen as preferred or least preferred at least once (see figure 4.12). Keyboard input type was most preferred with relatively high number of votes. It had also low number of votes on the least preferred list. Least preferred input type was gamepad, scoring high on the least preferred list and low on the most preferred list. Most controversial controller was the motion controller, scoring almost equal number of votes both as most and least preferred input type. Most common combinations of most and least preferred input devices were keyboard as best, motion as worst as well as motion as best and gamepad as worst (see figure 4.13)

When data was grouped by the input preference, there are some interesting differences with the game data and the questionnaire results (record runs, average runs, reset rate, SUS, PAD and GEQ scores). The average scores grouped by input preference can be seen in table 4.2 and in figure 4.14). By looking at the figures, we can see that the users tended to prefer controllers that they got better results with, as the most preferred control types had the highest record run distances, run distance averages and reset times compared to the least preferred controllers. This is supported by the fact that the PAD dominance dimension score was also higher than with least preferred controllers, indicating that the users felt more confident using these controllers than their least preferred ones.

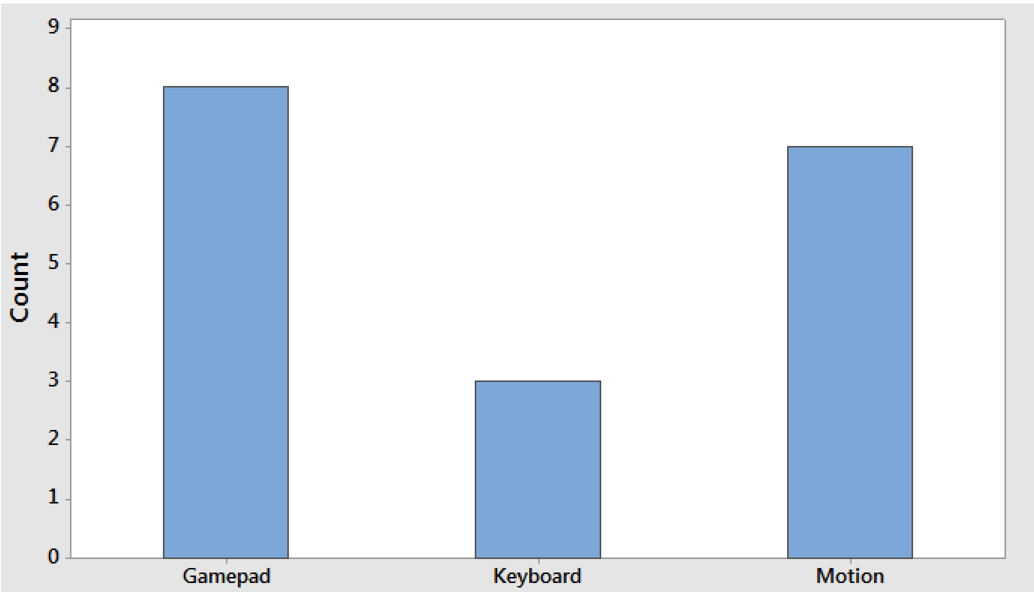
The answers to the open ended questions about controller preference for each controller type are analysed in the following sections.

4.4.1 Keyboard preference

The keyboard was clearly the most liked of the interfaces, with 8 users ranking it as their favorite and only 3 as their least favorite. The top reason for users selecting this type to their favorite seemed to be progress with the game. The users reported "progressing in the game", "getting the highest record", "getting further than 2 m" and "finding a strategy that actually took them forward". The users reported the keyboard to be the "easiest to control" or at least "having at least a little feeling of control". The users that liked this keyboard type liked that the effect of the inputs were more deterministic - "four values either on or off, which felt calmer and more controllable than the rest". Familiarity with the interface with original QWOP was also one of



(a) Most preferred input types.



(b) Least preferred input types.

Figure 4.12: Most and least preferred input types.

Input type	Preferred input	Run record	Average run	Reset rate	SUS	PAD	GEQ
All	Yes (18)	14.00	0.87	5.30	62.50	P=0.49, A=0.17, D=0.28	2.61
	- (18)	4.01	0.37	3.07	56.53	P=0.17, A=0.13, D=-0.04	2.30
	No (18)	2.48	0.39	2.81	43.89	P=0.04, A=0.07, D=-0.36	2.23
Keyboard	Yes (8)	22.88	1.30	9.23	53.13	P=0.31, A=-0.22, D=0.41	2.29
	- (7)	5.33	0.41	4.18	63.21	P=0.39, A=0.21, D=-0.18	2.58
	No (3)	2.58	0.46	5.14	61.67	P=0.50, A=0.33, D=-0.58	2.61
Gamepad	Yes (7)	4.14	0.46	3.05	68.33	P=0.75, A=0.08, D=0.08	3.00
	- (4)	3.38	0.28	2.86	58.93	P=0.43, A=0.14, D=-0.18	2.26
	No (7)	2.42	0.35	2.96	45.00	P=-0.13, A=-0.09, D=-0.47	2.12
Motion	Yes (7)	8.09	0.56	1.79	70.71	P=0.57, A=0.64, D=0.21	2.80
	- (4)	2.79	0.44	1.50	40.63	P=-0.69, A=-0.06, D=-0.19	1.89
	No (7)	2.50	0.42	1.64	35.00	P=0.04, A=0.14, D=-0.64	2.19

Table 4.2: Interface preference average statistics

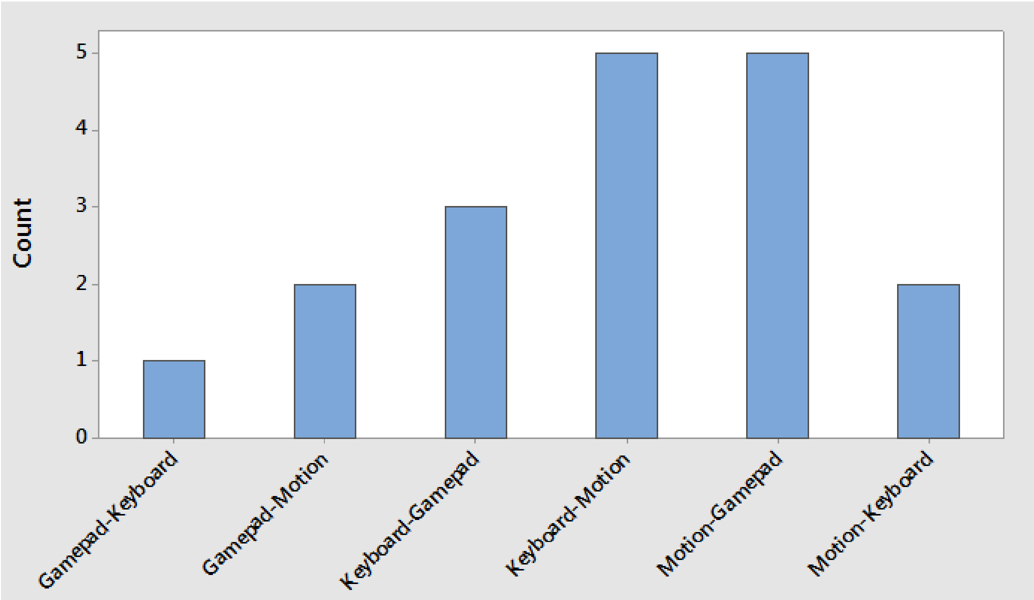


Figure 4.13: Most common most and least preferred combinations.

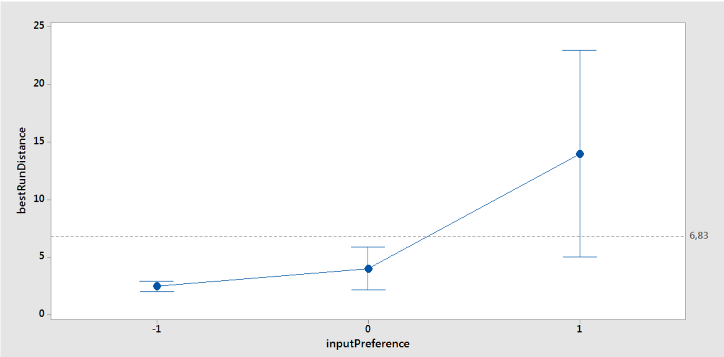
the reasons the keyboard was chosen as the favorite interface as some users reported that the interface felt “familiar” or that they had played QWOP before.

The players that disliked the keyboard control reported that the interface felt “less fun”, “not as immersive”, “not as exiting” and “felt completely different from the other two”.

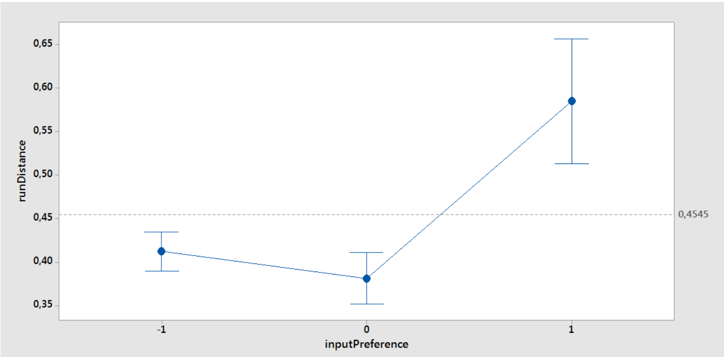
4.4.2 Analog preference

Analog controller was clearly the most disliked of the controller types, with only 3 users ranking it as their favorite type and 8 users ranking it as their least preferred input type. The users that preferred the controller type described is as “interesting”. This controller type was reported to be “easiest to get into the initial position” and that “it was easier to fall into the rhythm of motion with back and forth twin stick movement”. Getting a good score was also one of the reasons of choosing this interface as a preferred one.

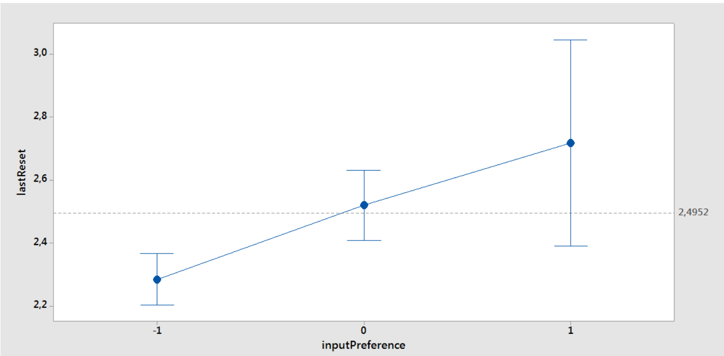
For most of the users the controller scheme was clearly too cryptic. The interface was described as “not intuitive”, “unclear”, “limited”, “unnatural”, “unusable” and “unable to master”. Most of the users reported having difficulties of figuring out which movement controls what and how each input affects the movement of the character on screen. Up and down stick motions



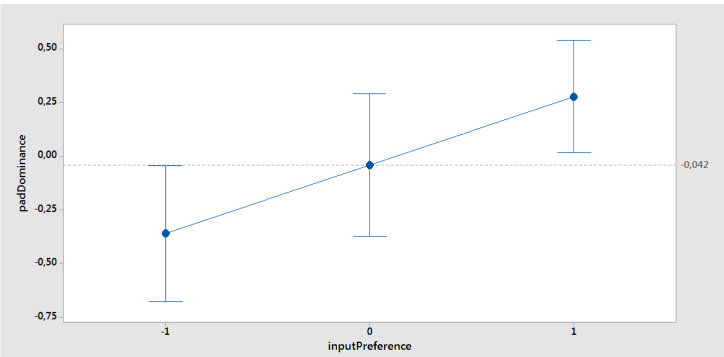
(a) Record run distance



(b) Run distance



(c) Reset rate



(d) PAD Dominance

Figure 4.14: Main effect plot of score distributions from least preferred (-1) to most preferred (1) controller

were reported to be especially unintuitive. The other major difficulty using the interface seemed to be the timing. The analog sticks had to be moved in very specific rhythm for the walking to be effective. The full range of movement offered by the sticks also seemed to make the interface more complex. The interface seemed “too sensitive, like the game itself was running faster” and that “the joysticks were a good way to control the amount and value of key presses but made the game harder to play”.

4.4.3 Motion preference

Of all the input types, the motion controller was the most divisive, with equal number of votes both as most favorite and least favorite. All of the users that had ranked the motion controller as their favorite interface reported that the interface felt “intuitive”, “natural”, “fluid” and most “real life like” of all the interfaces. Using the motion controller was like “controlling a puppet”, and the input type seemed to offer “richer input”, which made the motions of the character look more natural. Some of the users also liked the fact that they got to move more while using the interface and one user even reported that “it was nice how the physicality of the controller amplified the struggle of the game”. Some users really seemed to like this controller type and would have wished to use it more even though they considered that they would have to practise the input type more at first.

However, the motion controller seemed to suffer from some usability problems. Even some players who liked the motion control reported that the controller was “at first actually harder” or “liked it at first, but then got frustrated when the character started falling all the time”. This effect is even more prominent with users who disliked the motion controller. The users described the controller as “hard to control”, “unprecise” and “confusing”. The main offender for this controller type was keeping the hands in the right control zone. The users reported that “it was hard to get the controllers back into optimal initial placement to start fresh after each reset”. This effect was present even with users who reported liking the interface. One of the users reported also having difficulties using depth to control sideways movements of a character. Some users also reported having trouble figuring out what the controls where and what type of movement caused what type of movement with the character.

Chapter 5

Discussion

In the following sections we analyse the meaning of the results stated in chapter 4 and also evaluate factors that could have influenced results.

5.1 Effects of choice of interface on controllability

The results suggest that control interface implementation can affect the controllability of an physically based character. The choice of interface seemed to have an effect on how long walks the players could take with the character, how often they fell with the character and what kinds of record walks they could do with the character. As expected, the QWOP seemed to be overall an difficult game to play despite the controller type used to play it. Keeping the balance and attempting to walk with the character seemed to be very difficult, as the users fell down within seconds from the start of the run.

The trouble of using the interfaces to control the character reflected in the generally poor SUS scores from all of the controller types. The SUS score for all of the controllers was very low, with the average usability evaluated to be worse than 34% of products evaluated using the same questionnaire scale. All of the interfaces, including the original keyboard interface, seemed to suffer from some severe usability issues that hindered their performance.

Based on earlier results, we expected that the players using the motion controller would perform better compared to the other controller types, but despite this expectation, the motion controller did not outperform the other controller types in this examination. The players seemed to perform the best with the keyboard controller in terms of run records, run averages and reset rates. It is noteworthy however, that the run data gathered from the different input types contained some performance peaks caused by users who managed to get a particularly good run during a play session. The keyboard users made more good runs, and they also fell less with this controller type compared to the other controllers. This might have caused a bias to the run data results, so the differences between the controller types should be approached with caution.

The most frequent problem reported by the users was the control mapping related to controlling a physically based character with the interfaces. All the users seemed to have trouble figuring out which input causes what effect on the screen. The instructions used in the test did not help the users figure out how to use the controllers because the players either did not notice the instructions, or they could not figure out what the instructions meant in terms of their input.

For keyboard input, we expected that the users would have problems with the input mapping, because QWOP's fame for having an unintuitive control scheme. This seemed to be true with this test since the users seemed to have trouble figuring out what input does what in the game. The players usually expected one button to control one leg in the game.

Both of the IK-based controllers seemed to suffer from mapping issues as well. Most common problem was related to the undeterministic reactions to the user input; the friction with the ground sometimes prevented the leg from following the IK-target, which caused the input to seem broken or unresponsive to the players. The IK did not respond to some of the user inputs, like lifting the leg up fast enough, which made taking steps with the system difficult.

> "I can't figure out which [analog] stick controls which leg. I try to spin this around and nothing seems to happen."
>
> "Is this left [motion] controller broken? It doesn't seem to do anything."

With the gamepad controller, the biggest issue seemed to be the lag between the input and the IK-system. The player was required to hold and move the sticks in certain rhythm so that the leg could reach it's destinations and produce walking motions. For most of the users this type of input seemed to be really unintuitive, and the users were not able to figure out how to use the controllers to walk with the character. Some of the users tried to move the controller sticks around in rapid fashion and got frustrated when the character did not seem to react to their inputs. More direct input scheme could probably have worked better for this controller type. Mapping the different poses required for walking was difficult because of the limited two-dimensional range of the used gamepad, and its tendency to favor extreme values of input.

With the motion controller, most of the difficulty was caused by the lack of stability. This instability was caused mostly by the issues related to how the input from the user was captured. The use of an fixed calibration point meant that center point for calculating target leg positions chanced every time the users moved their base position - causing drifting when the error was allowed to accumulate over time. The direct mapping between the legs and the controller positions was an additional challenge for this game. The legs followed directly the positions of the user's hand, and after a level reset, the user's hand were usually positioned based on the positions at the end of the previous run. Using previous positions made the start state of the character undeterministic, causing some unnecessary resets for the users to search a stable starting point for the character's legs all over again. Most of the players also had trouble finding right radius to use their controls; some of the users moved their hands too little (resulting in baby steps that resembled walking, but could not keep the balance of the character for long) or too much (player trying to walk using only extreme positions). Some players also tried to use at first wrong axis to move the character (sideways motion) or only one axis (only upwards motion or only forwards motion) that prevented them from controlling the character effectively. This problem was related to the problem of knowing which bodily motions are relevant as input, as pointed out in the earlier research.

On the other hand, the users described the motion controller to feel more "natural to use" and despite the difficulties, most of the players figured out how to take realistic looking "babysteps" with the controller pretty quickly. Less usability issues and more stable stance for the character, would have probably helped the users to use the motion control interface, probably increasing it's preference rating.

However, despite the apparent differences how the users were able to control the character in the game, there were not any significant differences between the usability evaluations between the input types or controllers selected as most or least preferred. This could have been caused by the fact that the questionnaire could not necessarily differentiate the different interfaces well enough at tested usability level. Another reason could be the fact that some of the users stated that they had difficulties choosing which controller type they did and did not prefer because all of them had been very difficult to use.

5.2 Effects of choice of interface on playability and engagement

In general, the level of engagement varied a lot between the players from frustration to expressions of joy. The differences between the GEQ and PAD scores between the different input types were not significant. The individually analyzed PAD factors seemed to indicate that the gameplay experiences between the users varied quite much. Based on the observations and the written responses, some of the users really seemed to enjoy playing the game and concentrated hard on learning how to walk with the interface, even asking after the examination if they could get to play the game again some day. On the other hand, some of the players were clearly frustrated with the game and would have quit the play session if it was allowed in the examination.

> "Yep... This is just as frustrating as I remembered."

> "Do I really have to play QWOP for fifteen minutes? Why would anyone do this to their players?!"

> "At this state, if it weren't for the sake of the study, I'd put the controller down at this point."

The frustration experienced while playing the game might have been caused by the usability issues with the interface, since earlier research has stated the accessibility of controls to be one of the blockers that may prevent user from reaching engagement with the game. QWOP's reputation of being a hard and frustrating game may have affected the results as well as even seeing the game caused an immediate negative reaction to some players. For the new players, the clumsiness of the character and the constant falling seemed to have some novelty value as the comical splits and flips that the character made caused expressions of laughter. This hints that unpredictability of controls may indeed be an engagement source while playing an awkward physics game. For QWOP however, the usability issues seemed to outweigh this source of engagement for players who had tried the game before and had gotten frustrated with the original version with the game. The fact that the players were rewarded with a movie ticket for participation might have also influenced the results, since some players may have agreed to take part to the study just to get the ticket. This instrumental goal could have affected the player's ability to enjoy the game itself. Having played the game earlier might have also affected which control type the player choose as their preferred one, since some of the users stated that they picked keyboard as preferred because it was "familiar" or that "they had used it before".

The clearest source of engagement while playing the game seemed to be related to making progress in the game, indicating that QWOP facilitates hard-fun style of play. For even the frustrated players, learning how to produce movement, taking a few steps and beating their previous records made the players express achievement and joy.

> "Oh hey! I made a moon walk."

> "Hey! That actually looked like walking for a few seconds!"

The players also displayed some different play strategies while playing the game. The game mechanics of the character were built to support this. Players were allowed to use whatever movement styles they pleased as long as the head of the character would not hit the ground. While some of the users gave up walking pretty quickly, switching their goal from walking to trying to find out a new strategy that would allow them to move forward safely. Some other users tried their best to try to figure out a way to walk with the controllers, trying out different ways of inputs to see what works and what did not. Some users seemed to enjoy trying to master the difficult control scheme while the others users would have preferred more precise controls and were frustrated by the fact that they could not figure out how to proceed in the game. This statement is supported by the result that controllers that the users preferred scored better in terms of run records, run distances, reset rates and feelings of dominance.

The different control types seemed to favor different types of play strategies. The strategies that allowed the player to move safely forward disregarding realistic walking seemed to be win strategy for first time players. The keyboard control especially seemed to facilitate these types of strategies, because it allowed more precise and deterministic input how to position the legs of the character. IK interfaces on the other hand seemed to favour walking strategies, as the precise positioning of the legs was a lot harder because the undeterministic nature of the IK system. Almost all of the top scores in the test were result of figuring out a strategy how to slowly nudge the character forward without flipping it over. Examples of these strategies were keeping one knee down as anchor while nudging the character forward with the other leg (keyboard) or sliding down on the back while fidgeting the legs to pull the character forward (motion). Few of the keyboard users also discovered the leg-jitter bug, allowing them to easily but slowly proceed in the game without much effort. This favour towards safe strategies instead of walk strategies might have affected the results of the game in keyboard input devices favour.

> "This is kinda cheating... I'm not walking I'm sliding on my butt."

Bodily exertion from the movement controller was also noted to be a source of engagement that may have helped the motion interface reach its second place as most preferred control type despite its apparent usability flaws. The users who had ranked the motion controller as their preferred type mentioned that movement to be one of the reasons they liked the motion controller in addition to it's naturalness and intuitiveness. The difficult mapping also forced the users to search for the right input a bit more, which caused them to try out many different types of bodily movement leading to more potential to getting engagement from exertion. Novelty of the motion controller may have also affected the results judging by the written evaluations given by the users as the users who ranked the keyboard as their least preferred evaluated it to be "less fun" and "not as immersive" in comparison to the motion controller ranked as their preferred controller type.

5.3 Nature of difficulty when controlling a physically based character

The aim of this study was to provide an answer to a question whether difficulty of controlling a dynamic character is mainly caused by it's fundamental complexity or if this complexity is mainly caused by the use of unintuitive control schemes and interfaces. Unfortunately, based on the results of this study, the question could not be answered yet. The users clearly had difficulties when controlling the character in the test but based on results it was difficult to tell whether this difficulty was caused by the issues regarding the interface or the character control in general. At least we can say that controlling a dynamic, physically based character remained difficult even after our best efforts to provide a motion control interface with more precision and natural mapping than the original keyboard interface.

However, it is worth pointing out that the 5 minute play time seemed to be too long for playing a game like QWOP. The testers expressed getting tired while playing the game. Compared to the fact that some games can be easily played for hours, getting tired in the combined play time of 15 minutes seems surprising. The subject should be studied futher to figure out the exact cause, but it is possible that this fatigue can be caused by the fact that learning how to control a dynamic character is mentally a challenging task - especially without proper instructions how to use the controls. The player has to simultaneously:

1. Keep track of the characters current pose and position and the direction they are going.

2. Use the inputs to control the character and figure out how those inputs are connected to the movements of the character.

3. Remember how walking works and try to figure out how to use the inputs to produce walking motions with the virtual character.

This combined task is mentally challenging which may be even harder when combined with usability issues with the interface. All the three interfaces were tested after each other with very short break between the play sessions. This may have increased the cognitive load as the players had to unlearn the previous interface while starting to learn the new one. On the other hand, some of the players told that they felt like they benefited from learning from the previous interfaces because it allowed them to figure out how the walking in the game works and what types of strategies they can use in the game.

> "I'm trying to remember how humans walk again. Like when you should bend the leg to get reasonable steps. Managed to take a step but I forgot how I did it."

It is also worth pointing out that the ability to reset the level every time the player wanted to seemed to benefit the game when compared with the original design of the game where reset was only allowed after the runner crash. This allowed players to recover from failed game state more quickly, enabling players to iterate their game strategies faster. This design choice was guided by the fact that fast iteration time has been used successfully also in other very difficult games where the player dies often to ease up the frustration of failure (e.g. Super Meat Boy).

5.4 Evaluation

The results of this study are quite case specific and the results may not be generalizable. The testing methods used in this study do contain a lot of undetermined variation that can affect the validly and reliability of the results. The game itself suffered from some usability issues, and the different controllers were not validated to be equally usable before testing the game out with the end users. GEQ also may not be suitable questionnaire for the engagement evaluation for this type of game, since it is more geared towards highly immersive realistic and potentially violent games. There was also some variation in the testing environment used to gather the data from the end users that could have affected some of the test results (e.g. some of the tests were performed in an open space with a lot of background noise while the others were performed in quiet closed environments).

The study would have benefited from recording the play sessions, since the notes and observations are subjective ways to gather data and are prone to biases and errors of the researcher. The recordings would have provided more reliable data about the behaviour and play styles of the players during the play sessions. For the scope of this study analyzing video recordings was not feasible in terms of the effort that goes to analyzing them as well as getting a permission to record the event from the end users.

It is worth to point out that for testing purposes, the choice of developing a full game was not the best one. In most of the studies using a game as a testing method, the researchers rely on an already implemented games when testing the control interfaces. In this study, the QWOP clone was built from scratch, which increased the work load considerably. Developing a game took time that could have been used to put to research, testing the examination method, data gathering, result analyzing and writing. Fine tuning and testing the different interfaces was done with pilot test users, but developing the interfaces to a point of where they would be truly balanced would have taken much more time than the scope of this thesis would have allowed. On the other hand, developing a game enabled to test different settings and parameters with each input device, giving some first hand perspective of aspects that can be taken into account while developing an awkward physics game, which this study would have lacked otherwise.

Chapter 6

Conclusions

The goal of this thesis was to study possible sources of difficulty in controlling a physically based character and how the choice of interface can affect the controllability, playability and engagement in games where the main focus is directly controlling a physically based character. The main aim of this study was to provide an answer to a question whether difficulty in controlling a dynamic character is mainly caused by it's fundamental complexity or whether this complexity is mainly caused by the use of unintuitive control interfaces. Our hypothesis was that motion tracking could provide an easier way to control a physically based character. We were curious to see if easier controllability would affect the engagement of an awkward physics game in any way. We set out to investigate this from the point of view of awkward physics games - a game genre that embraces the complexity of controlling a physically based character instead of shying away from it. Not much research has been contributed to this interesting niche game genre, so one of the aims of this study was to provide insight of what issues the designers need to face when designing an interface for physically based directly controlled character for their games.

To investigate this, a test was implemented using both qualitative and quantitative research methods to gather information on how the choice of interface affected the controllability of a physically based character. For the test a QWOP clone was implemented with three different input devices featuring different levels of control abstraction between the actions of the user and the actions of the character. The test was carried out on the Aalto university campus area with 18 test participants.

Based on the results of the study, we were unfortunately unable to provide an answer to the question whether controlling a physically based character is difficult due to its complexity or due to the difficult control interfaces. The results however, seemed to suggest that controlling a dynamic character may have a steep learning curve and that controlling a dynamically animated character is cognitively a challenging task. One of the key aspects of making an experience like this enjoyable was to make sure that the players have a stable point to fall back on so that they can take a short break to figure out what to do before trying out something else. Constant failure with simple tasks, such as keeping balance seemed to create more frustration rather than engagement - especially with less motivated players. On the other hand, the challenge of controlling a dynamic character did engage some of the players, so the hard fun of mastering controls of the game may be a part of the core engagement of awkward physics games.

The results also showed that mapping between the input device and movements of the character and the usability of the interface can cause significant issues with controllability of dynamically animated character. Extra effort should be put to designing the interfaces to make sure that the users can intuitively grasp how to use the controls to affect the movements of the character. The users seemed to prefer controls that are clear and deterministic allowing the users to see clear connection between their actions and the actions of the character on the screen. The choice of interface and its usability may affect the gameplay in a way that different interfaces seem to facilitate different types of strategies to play the game.

Each of the interfaces implemented in this study had their own usability issues regarding controlling a physically based character. With the original keyboard input, the users struggled to figure out what each button was supposed to do because of the odd control scheme. The users seemed to think that each button was supposed to control one leg when in reality all of the buttons controlled all of the feet simultaneously. The benefit of using this type of control seemed to be that with the binary type of input the users could try out and more easily grasp what each input was supposed to do whereas in the IK the controls were less deterministic. With the IK control, the interactions with the virtual world that sometimes prevented the character from following the instructions of the player. Undeterministic controls caused confusion among the players and seemed to prevent players from seeing the connection between their actions and the actions of the character on screen. The more deterministic input seemed to make the player feel like that they had more control and they had a chance of figuring out how the interface works.

Regarding controlling a dynamic character, the results seem to suggest that the motion controller combined with IK could be a good and engaging way to control the complexity of controlling a dynamic character. The key factors that contributed to the engagement of this controller type seemed to be bodily extension, fluidity of motion and more natural interaction with the interface. In this study however, the usability of the motion control interface was the main factor that limited the experience both for those who enjoyed the interface and those who didn't. More development time spent refining the usability of the interface and more sophisticated motion tracking algorithms could help more users to learn how to use the interface.

The analog interface (gamepad sticks) seemed to suffer from severe usability issues that limited player's performance with the interface. Having an analog type of control didn't seem to help with the controllability in this case. On the contrary, it made the controllability even a bit harder. One of the reasons was that the value range provided by the selected gamepad device was limited and difficult to map to the IK system. The users also tended to prefer using the extreme values of the controller stick instead of small movements. This seemed to suggest that the gamepad interfaces may not be the best choice of control device for abstracted limb control if timing and rhythmic movement of action are required. The analog interface has been used more successfully to control some aspect of the character directly (e.g. controlling the bending of a bread slice in I am Bread) or for more slow phased higher level control (e.g. guiding the end position of character's hand in Octodad or Surgeon simulator).

For futher study, it would be interesting to investigate the relationships between the control interface and character controllability in more detail. It could be useful to test out the different parameters individually so that the effects of each item on the overall controllability, playability or engagement would be easier to distinguish. Possible ways to approach this would be testing out how the level of control abstraction affects the character controllability or which controller types facilitate certain types of abstraction the best. It would be also interesting to study specifically the motion controllers to see how they can be used to enhance the controllability of a physically based character and what type of control mapping and control abstraction works the best for this type of input device.

The study methods used in this study had some problems regarding validly and reliability of the results due to limited time to balance out the different interfaces with the QWOP clone. There were also some suitability problems with the questionnaires chosen for the study. Despite flaws with the study setup, the study should offer some perspective on what pitfalls and what usability problems to avoid when developing a control scheme for an physically based character. The study also highlighted some of the potential sources of engagement for this type of game that could be explored in more detail in the future. The main contributions of this study are providing insight to the sources or engagement and usability issues related to a mostly unexplored game genre. It also works as an overview of research related to the subject of controlling a physically based character.

Bibliography

[1] Sami Abuhamdeh, Mihaly Csikszentmihalyi, and Baland Jalal. Enjoying the possibility of defeat: Outcome uncertainty, suspense, and intrinsic motivation. *Motivation and Emotion*, 39(1):1–10, September 2014. ISSN 0146-7239, 1573-6644. doi: 10.1007/s11031-014-9425-2. URL http://link.springer.com/article/10.1007/s11031-014-9425-2.

[2] Nadia Bianchi-Berthouze. Understanding the role of body movement in player engagement. *Human Computer Interaction*, 28(1):40–75, May 2012. ISSN 0737-0024. doi: 10.1080/07370024.2012.688468. URL http://www.tandfonline.com/doi/abs/10.1080/07370024.2012.688468.

[3] The Hidden Blade. Qwop running tutorial [video file], 2012. URL http://youtu.be/HBFYJvq_o_4. [Online; Retrieved 16-10-2014].

[4] Randolph Blake and Robert Sekuler. *Perception*, chapter Action and the perception of events, pages 317–352. McGraw-Hill, Boston, 5th edition, August 2005. ISBN 9780072887600.

[5] Elizabeth A. Boyle, Thomas M. Connolly, Thomas Hainey, and James M. Boyle. Engagement in digital entertainment games: A systematic review. *Computers in Human Behavior*, 28(3):771–780, May 2012. ISSN 0747-5632. doi: 10.1016/j.chb.2011.11.020. URL http://www.sciencedirect.com/science/article/pii/S0747563211002640.

[6] Margaret M. Bradley and Peter J. Lang. Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, 25(1):49–59, March 1994. ISSN 0005-7916. doi: 10.1016/0005-7916(94)90063-9. URL http://www.sciencedirect.com/science/article/pii/0005791694900639.

[7] Jeanne H. Brockmyer, Christine M. Fox, Kathleen A. Curtiss, Evan McBroom, Kimberly M. Burkhart, and Jacquelyn N. Pidruzny. The

development of the game engagement questionnaire: A measure of engagement in video game-playing. *Journal of Experimental Social Psychology*, 45(4):624–634, July 2009. ISSN 0022-1031. doi: 10.1016/j.jesp.2009.02.016. URL http://www.sciencedirect.com/science/article/pii/S0022103109000444.

[8] John Brooke. SUS – a quick and dirty usability scale. *Usability evaluation in industry*, 189:194, 1996. URL http://cui.unige.ch/isi/icle-wiki/_media/ipm:test-suschapt.pdf.

[9] Emily Brown and Paul Cairns. A grounded investigation of game immersion. In *CHI '04 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '04, pages 1297–1300, New York, NY, USA, 2004. ACM. ISBN 1-58113-703-6. doi: 10.1145/985921.986048. URL http://doi.acm.org/10.1145/985921.986048.

[10] Francesco Cafaro, Leilah Lyons, Raymond Kang, Josh Radinsky, Jessica Roberts, and Kristen Vogt. Framed Guessability: Using Embodied Allegories to Increase User Agreement on Gesture Sets. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction*, TEI '14, pages 197–204, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2635-3. doi: 10.1145/2540930.2540944. URL http://doi.acm.org/10.1145/2540930.2540944.

[11] Bruno Cardoso, Teresa Romão, and Nuno Correia. CAAT: A discrete approach to emotion assessment. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '13, pages 1047–1052, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-1952-2. doi: 10.1145/2468356.2468543. URL http://doi.acm.org/10.1145/2468356.2468543.

[12] Mark Chen, Beth E Kolko, Elizabeth Cuddihy, and Eliana Medina. Modeling and measuring engagement in computer games. In *DIGRA Conf.*, Vancouver, Canada, 2005. Paper presented at the annual conference for the Digital Games Research Association (DiGRA).

[13] Dormann Claire and Boutet Mish. Incongruous Avatars and Hilarious Sidekicks: Design Patterns for Comical Game Characters. In *DiGRA '13 - Proceedings of the 2013 DiGRA International Conference: DeFragging Game Studies*, 2014. ISBN ISSN 2342-9666. URL http://www.digra.org/wp-content/uploads/digital-library/paper_58.pdf.

[14] Claire Dormann. Fools, tricksters and jokers: Categorization of humor in gameplay. In Dennis Reidsma, Insook Choi, and Robin Bar-

gar, editors, *Intelligent Technologies for Interactive Entertainment*, volume 136 of *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, pages 81–90. Springer International Publishing, 2014. ISBN 978-3-319-08188-5. doi: 10.1007/978-3-319-08189-2_10. URL http://dx.doi.org/10.1007/978-3-319-08189-2_10.

[15] Laura Ermi and Frans Mäyrä. Fundamental components of the gameplay experience: Analysing immersion. In *DiGRA '05 - Proceedings of the 2005 DiGRA International Conference: Changing Views: Worlds in Play*, 2005. ISBN ISSN 2342-9666. URL http://www.digra.org/wp-content/uploads/digital-library/06276.41516.pdf.

[16] Christine M. Fox and Jeanne H. Brockmyer. The Development of the Game Engagement Questionnaire: A Measure of Engagement in Video Game Playing: Response to Reviews. *Interacting with Computers*, 25 (4):290–293, July 2013. ISSN 0953-5438, 1873-7951. doi: 10.1093/iwc/iwt003. URL http://iwc.oxfordjournals.org/content/25/4/290.

[17] Bennett Froddy. Qwop [game], 2008. URL http://www.foddy.net/Athletics.html. [Online; Retrieved 16-10-2014].

[18] Thomas Geijtenbeek and Nicolas Pronost. Interactive Character Animation Using Simulated Physics: A State-of-the-Art Review. *Computer Graphics Forum*, 31(8):2492–2515, December 2012. ISSN 01677055. doi: 10.1111/j.1467-8659.2012.03189.x. URL http://doi.wiley.com/10.1111/j.1467-8659.2012.03189.x.

[19] Kathrin M. Gerling, Matthias Klauser, and Joerg Niesenhaus. Measuring the Impact of Game Controllers on Player Experience in FPS Games. In *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*, MindTrek '11, pages 83–86, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0816-8. doi: 10.1145/2181037.2181052. URL http://doi.acm.org/10.1145/2181037.2181052.

[20] Stephen W. Gilroy, Marc Cavazza, and Maurice Benayoun. Using Affective Trajectories to Describe States of Flow in Interactive Art. In *Proceedings of the International Conference on Advances in Computer Enterntainment Technology*, ACE '09, pages 165–172, New York, NY, USA, 2009. ACM. ISBN 978-1-60558-864-3. doi: 10.1145/1690388.1690416. URL http://doi.acm.org/10.1145/1690388.1690416.

[21] Wijnand Ijsselsteijn, Wouter van den Hoogen, Christoph Klimmt, Yvonne de Kort, Craig Lindley, Klaus Mathiak, Karolien Poels, Niklas Ravaja, Marko Turpeinen, and Peter Vorderer. Measuring the Experience of Digital Game Enjoyment. pages 88–89, 2008. URL http://www.noldus.com/mb2008/individual_papers/Symposium%20vanderHeijden/Symposium_vanderHeijden_IJsselsteijn.pdf.

[22] H. Irtel. The PXLab self-assessment-manikin scales, 2008. URL http://irtel.uni-mannheim.de/pxlab/demos/index_SAM.html. [Online; Retrieved 08-01-2015].

[23] Aki Järvinen. *Games without Frontiers: Theories and Methods for Game Studies and Design*. Tampere University Press, 2008. ISBN 978-951-44-7252-7. URL http://tampub.uta.fi/handle/10024/67820.

[24] Otto Lappi and Pauli Brattico. *Cog101 Johdatus Kognitiotieteeseen*, chapter Muisti. Helsingin yliopisto, 2008. URL http://www.helsinki.fi/kognitiotiede/kurssit/salaiset_kansiot/cog101/cog101_muisti.pdf. [course material].

[25] Joseph Laszlo, Michiel van de Panne, and Eugene Fiume. Interactive control for physically-based animation. In *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '00, pages 201–208, New York, NY, USA, 2000. ACM Press/Addison-Wesley Publishing Co. ISBN 1-58113-208-5. doi: 10.1145/344779.344876. URL http://dx.doi.org/10.1145/344779.344876.

[26] Nicole Lazzaro. Why we play games: Four keys to more emotion without story, March 2004. URL http://xeodesign.com/xeodesign_whyweplaygames.pdf. [Online; Retrieved 12-05-2015].

[27] Karen C. Liu and Victor B. Zordan. Natural user interface for physics-based character animation. In JanM. Allbeck and Petros Faloutsos, editors, *Motion in Games*, volume 7060 of *Lecture Notes in Computer Science*, pages 1–14. Springer Berlin Heidelberg, 2011. ISBN 978-3-642-25089-7. doi: 10.1007/978-3-642-25090-3_1. URL http://dx.doi.org/10.1007/978-3-642-25090-3_1.

[28] Mitchell McEwan, Daniel Johnson, Peta Wyeth, and Alethea Blackler. Videogame Control Device Impact on the Play Experience. In *Proceedings of The 8th Australasian Conference on Interactive Entertainment: Playing the System*, IE '12, pages 18:1–18:3, New York, NY, USA, 2012.

ACM. ISBN 978-1-4503-1410-7. doi: 10.1145/2336727.2336745. URL http://doi.acm.org/10.1145/2336727.2336745.

[29] Mitchell W. McEwan, Alethea L. Blackler, Daniel M. Johnson, and Peta A. Wyeth. Natural Mapping and Intuitive Interaction in Videogames. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play*, CHI PLAY '14, pages 191–200, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-3014-5. doi: 10.1145/2658537.2658541. URL http://doi.acm.org/10.1145/2658537.2658541.

[30] Elisa D. Mekler, Julia Ayumi Bopp, Alexandre N. Tuch, and Klaus Opwis. A Systematic Review of Quantitative Studies on the Enjoyment of Digital Entertainment Games. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*, CHI '14, pages 927–936, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2473-1. doi: 10.1145/2556288.2557078. URL http://doi.acm.org/10.1145/2556288.2557078.

[31] Jeanne Nakamura and Mihaly Csikszentmihalyi. The Concept of Flow. In *Flow and the Foundations of Positive Psychology*, pages 239–263. Springer Netherlands, 2014. ISBN 978-94-017-9087-1, 978-94-017-9088-8. URL http://link.springer.com/chapter/10.1007/978-94-017-9088-8_16.

[32] Anton Nijholt, Marco Pasch, Betsy van Dijk, Dennis Reidsma, and Dirk Heylen. Observations on experience and flow in movement-based interaction. In David England, editor, *Whole Body Interaction*, Human-Computer Interaction Series, pages 101–119. Springer London, January 2011. ISBN 978-0-85729-432-6, 978-0-85729-433-3. URL http://link.springer.com/chapter/10.1007/978-0-85729-433-3_9.

[33] Kent L. Norman. GEQ (Game Engagement/Experience Questionnaire): A Review of Two Papers. *Interacting with Computers*, 25(4):278–283, July 2013. ISSN 0953-5438, 1873-7951. doi: 10.1093/iwc/iwt009. URL http://iwc.oxfordjournals.org/content/25/4/278.

[34] Juliet Norton, Chadwick A. Wingrave, and Joseph J. LaViola, Jr. Exploring Strategies and Guidelines for Developing Full Body Video Game Interfaces. In *Proceedings of the Fifth International Conference on the Foundations of Digital Games*, FDG '10, pages 155–162, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-937-4. doi: 10.1145/1822348.1822369. URL http://doi.acm.org/10.1145/1822348.1822369.

[35] David Pinelle, Nelson Wong, and Tadeusz Stach. Heuristic evaluation for games: Usability principles for video game design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, pages 1453–1462, New York, NY, USA, 2008. ACM. ISBN 978-1-60558-011-1. doi: 10.1145/1357054.1357282. URL `http://doi.acm.org/10.1145/1357054.1357282`.

[36] James Portnow, Daniel Floyd, and Allison Theus. Extra credits: Kinect disconnect [video file], 2012. URL `http://youtu.be/ijcezUy3ZzY`. [Online; Retrieved 01-03-2015].

[37] Hua Qin, Pei-Luen Patrick Rau, and Gavriel Salvendy. Effects of different scenarios of game difficulty on player immersion. *Interacting with Computers*, 22(3):230–239, May 2010. ISSN 0953-5438. doi: 10.1016/j.intcom.2009.12.004. URL `http://www.sciencedirect.com/science/article/pii/S095354380900109X`.

[38] Steven Ray, Vahl Scott Gordon, and Laurent Vaucher. Evolving QWOP gaits. In *Proceedings of the 2014 Conference on Genetic and Evolutionary Computation*, GECCO '14, pages 823–830, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2662-9. doi: 10.1145/2576768.2598248. URL `http://doi.acm.org/10.1145/2576768.2598248`.

[39] RedLynx. Trials evolution [game], 2012. URL `http://www.redlynx.com/trials-evolution`. [Online; Retrieved 13-02-2015].

[40] Jeff Sauro. Measuring usability with the system usability scale (SUS). Measuring Usability LLC, 2011. URL `http://www.measuringu.com/sus.php`. [Online; Retrieved 25-04-2015].

[41] Jeff Sauro and James R. Lewis. When designing usability questionnaires, does it hurt to be positive? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '11, pages 2215–2224, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0228-9. doi: 10.1145/1978942.1979266. URL `http://doi.acm.org/10.1145/1978942.1979266`.

[42] Richard A. Schmidt and Craig A. Wrisberg. *Motor Learning and Performance*. Human Kinetics, January 2004. ISBN 9780736045667.

[43] Hampus Söderström. Toribash [game], 2010. URL `http://www.toribash.com/`. [Online; Retrieved 13-02-2015].

[44] Takaaki Shiratori and Jessica K. Hodgins. Accelerometer-based User Interfaces for the Control of a Physically Simulated Character. In *ACM*

SIGGRAPH Asia 2008 Papers, SIGGRAPH Asia '08, pages 123:1–123:9, New York, NY, USA, 2008. ACM. ISBN 978-1-4503-1831-0. doi: 10.1145/1457515.1409076. URL http://doi.acm.org/10.1145/1457515.1409076.

[45] Paul Skalski, Ron Tamborini, Ashleigh Shelton, Michael Buncher, and Pete Lindmark. Mapping the road to fun: Natural video game controllers, presence, and game enjoyment. *New Media & Society*, 13 (2):224–242, March 2011. ISSN 1461-4448, 1461-7315. doi: 10.1177/1461444810370949. URL http://nms.sagepub.com/content/13/2/224.

[46] J. Smith. Realistic summer sports simulator [game], 2012. URL http://gamejolt.com/games/sports/realistic-summer-sports-simulator/9769/. [Online; Retrieved 13-02-2015].

[47] Bossa Studios. Surgeon simulator [game], 2013. URL http://www.bossastudios.com/games/surgeon-simulator/. [Online; Retrieved 13-02-2015].

[48] Bossa Studios. I am bread [game], 2015. URL http://www.bossastudios.com/games/i-am-bread/. [Online; Retrieved 13-02-2015].

[49] Jaroslav Švelch. Comedy of Contingency: Making Physical Humor in Video Game Spaces. *International Journal of Communication*, 8(0):23, September 2014. ISSN 1932-8036. URL http://ijoc.org/index.php/ijoc/article/view/2687.

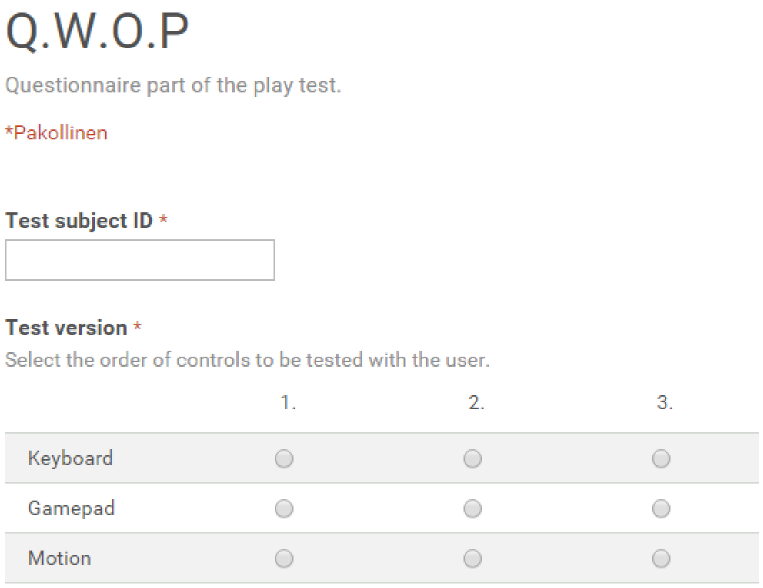
[50] Zachary O. Toups, Igor Dolgov, and Elizabeth M. Bonsignore. A Theory of Game Mechanic Signaling for Interface Design. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play*, CHI PLAY '14, pages 445–446, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-3014-5. doi: 10.1145/2658537.2661318. URL http://doi.acm.org/10.1145/2658537.2661318.

[51] Phil Turner. The Anatomy of Engagement. In *Proceedings of the 28th Annual European Conference on Cognitive Ergonomics*, ECCE '10, pages 59–66, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-946-6. doi: 10.1145/1962300.1962315. URL http://doi.acm.org/10.1145/1962300.1962315.

[52] DePaul University. Octodad [game], 2010. URL http://octodadgame.com/games/. [Online; Retrieved 13-02-2015].

Appendix A

Q.W.O.P questionnaire



Q.W.O.P

Questionnaire part of the play test.

*Pakollinen

Test subject ID *

Test version *

Select the order of controls to be tested with the user.

	1.	2.	3.
Keyboard			
Gamepad			
Motion			

Figure A.1: Pre-test questionaire

Preliminary Questionaire

Age *

Gender *

- Male
- Female

How often do you play games? *

- Never
- Rarely
- Sometimes
- Often
- Very often

How many hours per week do you play games on average? *

How often do you use the following controller types to play games? *

	Never	Rarely	Sometimes	Often	Very often
Keyboard and mouse					
Gamepad (Playstation controller, Xbox controller)					
Motion controller (Wii, Playstation Move, Razer Hydra)					
Full-body motion controller (Kinect, EyeToy, Webcam)					

Rate the controller types in order of preference. *

1= most preferred, 4=least preferred.

	1	2	3	4
Keyboard and mouse				
Gamepad (Playstation controller, Xbox controller)				
Motion controller (Wii, Playstation Move, Razer Hydra)				
Full-body motion controller (Kinect, EyeToy, Webcam)				

Figure A.2: Preliminary questionaire - part 1

What games or game genres do you usually play?

Which of the games listed below have you played?

Select all that apply.

- [ ] Qwop
- [ ] Octodad
- [ ] I Am Bread
- [ ] Surgeon Simulator
- [ ] Real Summer Sports Simulator
- [ ] Toribash
- [ ] Trials

How much do you know about playing QWOP? *

- ○ I don't know this game
- ○ I have heard about it but haven't played it
- ○ I have tried it once or twice but never made much progress in the game
- ○ I can walk or run steadily, but I have never beaten the game
- ○ I can walk or run the required 100m to beat the game

Figure A.3: Preliminary questionaire - part 2

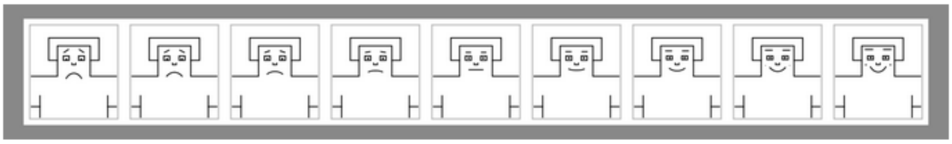
Game trial: 1

Answer the questions based on your experiences from last game trial.

Which of the controllers did you use in this trial? *

- Keyboard
- Gamepad
- Motion controller

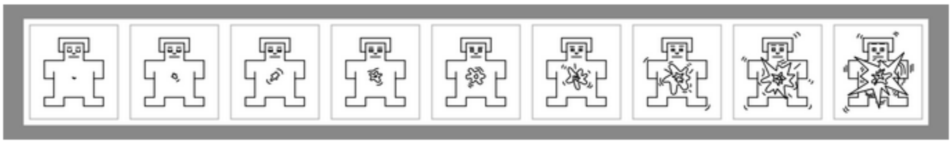
Select image from each row that best describes your overall emotion while playing the game.



*

Select image from the first image row that describes the pleasure of the experience.

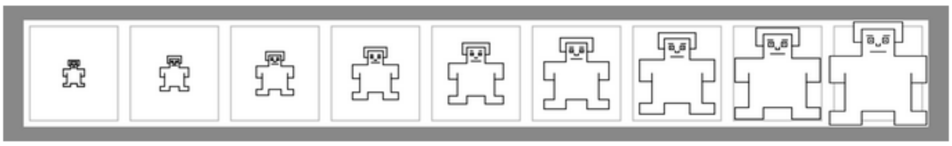
1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○



*

Select image from the second image row that describes the intensity of the experience.

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○



*

Select image from the third image row that describes the feeling of control of the experience.

1	2	3	4	5	6	7	8	9
○	○	○	○	○	○	○	○	○

Figure A.4: Playtest questionaire - part 1

Answer the following questions based on your overall experience while playing the game. *

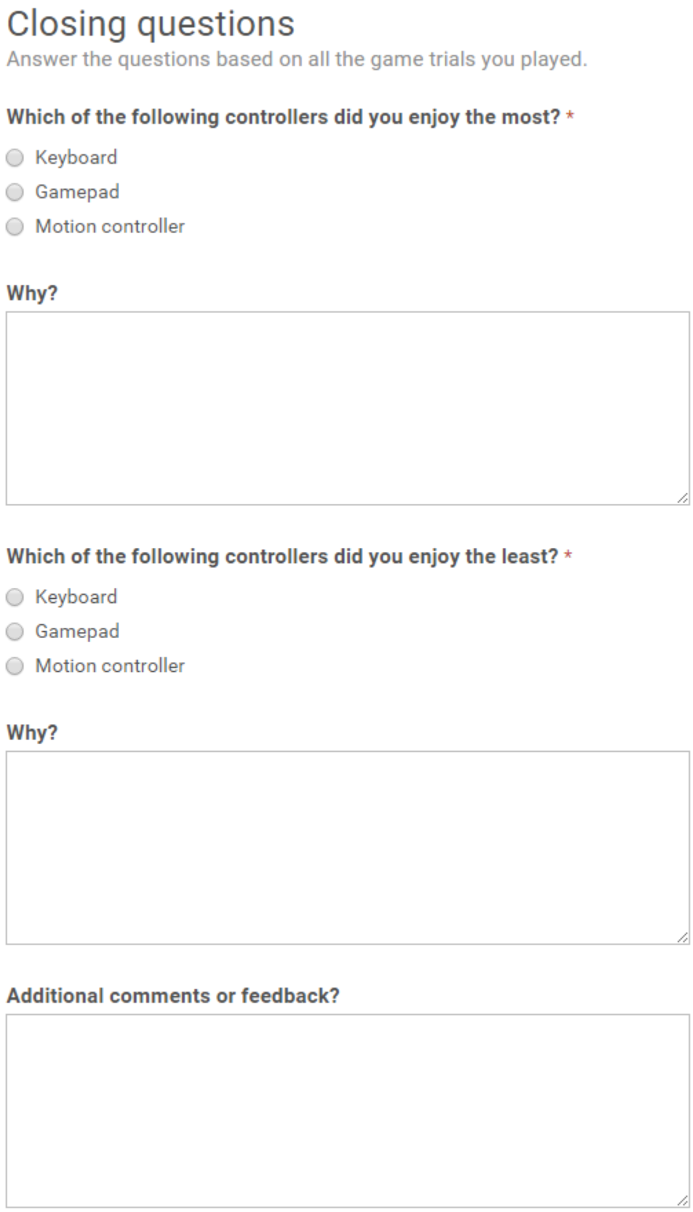
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I feel spaced out, disoriented or lost in thought	○	○	○	○	○
If someone talks to me, I don't hear them	○	○	○	○	○
Playing makes me feel calm	○	○	○	○	○
The game feels real	○	○	○	○	○
I lose track of where I am	○	○	○	○	○
I play longer than I meant to	○	○	○	○	○
Things seem to happen automatically	○	○	○	○	○
I lose track of time	○	○	○	○	○
Playing seems automatic	○	○	○	○	○
I feel like I just can't stop playing	○	○	○	○	○
My thoughts go fast	○	○	○	○	○
Time seems to kind of stand still or stop	○	○	○	○	○
I get wound up, tense or wired	○	○	○	○	○
I feel different	○	○	○	○	○
I play without thinking about how to play	○	○	○	○	○
I feel scared	○	○	○	○	○
I can't tell that I'm getting tired	○	○	○	○	○
I don't answer when someone talks to me	○	○	○	○	○
I really get into the game	○	○	○	○	○

Figure A.5: Playtest questionaire - part 2

Answer the following questions based on your experience with the game controller. *

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I found the interface to be simple.					
I found the interface very intuitive.					
I found that various functions in the interface were well integrated.					
I would imagine that most people would learn how to use the interface very quickly.					
I think that I would like to use the interface frequently.					
I could use the interface without having to learn anything new.					
I think that I could use the interface without the support of a technical person.					
I thought there was a lot of consistency in the interface.					
I felt confident using the interface.					
I thought that the interface was easy to use.					

Figure A.6: Playtest questionaire - part 3



Closing questions

Answer the questions based on all the game trials you played.

Which of the following controllers did you enjoy the most? *

- Keyboard
- Gamepad
- Motion controller

Why?

Which of the following controllers did you enjoy the least? *

- Keyboard
- Gamepad
- Motion controller

Why?

Additional comments or feedback?

Figure A.7: Ending questionaire